1. PROJECT REVIEW

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The United States' first manned space flight project was successfully accomplished in a 4⅔ year period of dynamic activity which saw more than 2,000,000 people from many major government agencies and much of the aerospace industry combine their skills, initiative, and experience into a national effort. In this period, six manned space flights were accomplished as part of a 25-flight program. These manned space flights were accomplished with complete pilot safety and without change to the basic Mercury concepts. It was shown that man can function ably as a pilot-engineer-experimenter without undesirable reactions or deteriorations of normal body functions for periods up to 34 hours of weightless flight.

Directing this large and fast moving project required the development of a management structure and operating mode that satisfied the requirement to mold the many different entities into a workable structure. The management methods and techniques so developed are discussed. Other facets of the Mercury experience such as techniques and philosophies developed to insure well-trained flight and ground crews and correctly prepared space vehicles are discussed. Also, those technical areas of general application to aerospace activities that presented obstacles to the accomplishment of the project are briefly discussed. Emphasis is placed on the need for improved detail design guidelines and philosophy, complete and appropriate hardware qualification programs, more rigorous standards, accurate and detailed test procedures, and more responsive configuration control techniques.

Introduction

The actual beginning of the effort that resulted in manned space flight cannot be pinpointed although it is known that the thought has been in the mind of man throughout recorded history. It was only in the last decade, however, that technology had developed to the point where man could actually transform his ideas into hardware to achieve space flight. Specific studies and tests conducted by government and industry culminating in 1958 indicated the feasibility of manned space flight. Implementation was initiated to establish a national manned space-flight project, later named Project Mercury, on October 7, 1958.

The life of Project Mercury was about 4⅔ years, from the time of its official go-ahead to the completion of the 34-hour orbital mission of Astronaut Cooper. During this period, much has been learned about man's capabilities in the space environment and his capabilities in earthbound activities which enabled the successful accomplishment of the objectives of the Mercury Project in this relatively short period. It is the purpose of this paper to review the more significant facets of the project beginning with the objectives of the project and the guidelines which were established to govern the activity. As in any form of human endeavor, there are certain signs which serve as the outward indication of activity and progress. For the Mercury Project, these signs were the major full-scale flight tests. These tests will be reviewed with particular emphasis on schedule, the individual mission objectives, and the results from each mission. Then, the organization with which management directed the

activities of Project Mercury will be explained, particularly with respect to those internal interfaces between major segments of NASA and those external interfaces with contractors and other governmental departments. The resources expended during the project will be explained with discussions on manpower and cost. In addition, the major results of the project will be discussed as will those areas which presented severe obstacles to technical progress.

This paper is primarily a review; greater detail in many of the areas discussed can be obtained by reference to other papers in this document and to the documents listed in the bibliography.

Objectives and Guidelines

The objectives of the Mercury Project, as stated at the time of project go-ahead, were as follows:

(1) Place a manned spacecraft in orbital flight around the earth.

(2) Investigate man's performance capabilities and his ability to function in the environment of space.

(3) Recover the man and the spacecraft safely.

After the objectives were established for the project, a number of guidelines were established to insure that the most expedient and safest approach for attainment of the objectives was followed. The basic guidelines that were established are as follows:

(1) Existing technology and off-the-shelf equipment should be used wherever practical.

(2) The simplest and most reliable approach to system design would be followed.

(3) An existing launch vehicle would be employed to place the spacecraft into orbit.

(4) A progressive and logical test program would be conducted.

More detailed requirements for the spacecraft were established as follows:

(1) The spacecraft must be fitted with a reliable launch-escape system to separate the spacecraft and its crew from the launch vehicle in case of impending failure.

(2) The pilot must be given the capability of manually controlling spacecraft attitude.

(3) The spacecraft must carry a retrorocket system capable of reliably providing the necessary impulse to bring the spacecraft out of orbit.

(4) A zero-lift body utilizing drag braking would be used for reentry.

(5) The spacecraft design must satisfy the requirements for a water landing.

It is obvious by a casual look at the spacecraft (fig. 1–1) that requirements (1), (3), and (4) were followed as evidenced by the escape tower, the retrorocket system that can be seen on the blunt end of the spacecraft, and the simple blunt-body shape without wings. Items (2) and (5) have been made apparent by the manner in which the astronaut has manually controlled the attitude of the spacecraft during orbital maneuvers, retrofire, and reentry, and by the recovery of the spacecraft and astronauts after each flight by recovery forces which included aircraft carriers and destroyers.

Basically, the equipment used in the spacecraft was derived from off-the-shelf equipment or through the direct application of existing technology, although some notable exceptions were made in order to improve reliability and flight safety. These exceptions include:

(1) An automatic blood-pressure measuring system for use in flight.

(2) Instruments for sensing the partial pressures of oxygen and carbon dioxide in the oxygen atmosphere of the cabin and suit, respectively.

Some may argue with the detailed way in which the second basic guideline of simplicity was carried out; however, this guideline was carried out to the extent possible within the volume, weight, and redundancy requirements imposed upon the overall system. The effect of the weight and volume constraints, of course, resulted in smaller and lighter equipment that could not always be packaged in an optimum way for simplicity.

Redundancy probably increased the complexity of the systems more than any other requirement. Because the spacecraft had to be qualified by space flight first without a man onboard and then because the reactions of man and his capabilities in the space environment were unknown, provisions for a completely automatic operation of the critical spacecraft functions were provided. To insure reliable operation, these automatic systems were backed up by redundant automatic systems.

The third guideline was satisfied by an adap-

tation of an existing missile, the Atlas. The modifications to this launch vehicle for the use in the Mercury Project included the addition of a means to sense automatically impending catastrophic failure of the launch vehicle and provisions to accommodate a new structure that would form the transition between the upper section of the launch vehicle and the spacecraft. Also, the pilot-safety program was initiated to insure the selection of quality components.

Application of the fourth guideline is illustrated by the major flight schedule which is discussed in the next section.

Major Flight Schedules

Planned Flight Test Schedule

The Mercury flight schedule that was planned early in 1959 is shown in figure 1–2. These are the major flight tests and include all those scheduled flight tests that involved rocket-propelled full-scale spacecraft, including boilerplate and production types. The planned flight test program shows 27 major launchings. There are three primary types of tests included in these, one type being the research-and-development tests, another being primarily flight-qualification of the production spacecraft, and the third being the manned orbital flight tests. In addition, the tests with the Mercury-Redstone launch vehicle provided some early ballistic flights for pilot training. Involved in the planned flight-test program were four basic types of launch vehicles, the Little Joe, the Mercury-Redstone, the Mercury-Jupiter, and the Mercury-Atlas.

Four Little Joe flights and two of the Atlas powered flights, termed Big Joe, were planned to be in the research and development category to check the validity of the basic Mercury concepts.

The qualification program was planned to use each of the four different launch vehicles. The operational concept of the qualification program provided for a progressive build-up of flight-test system complexity and flight-test conditions. It was planned that the operation of all

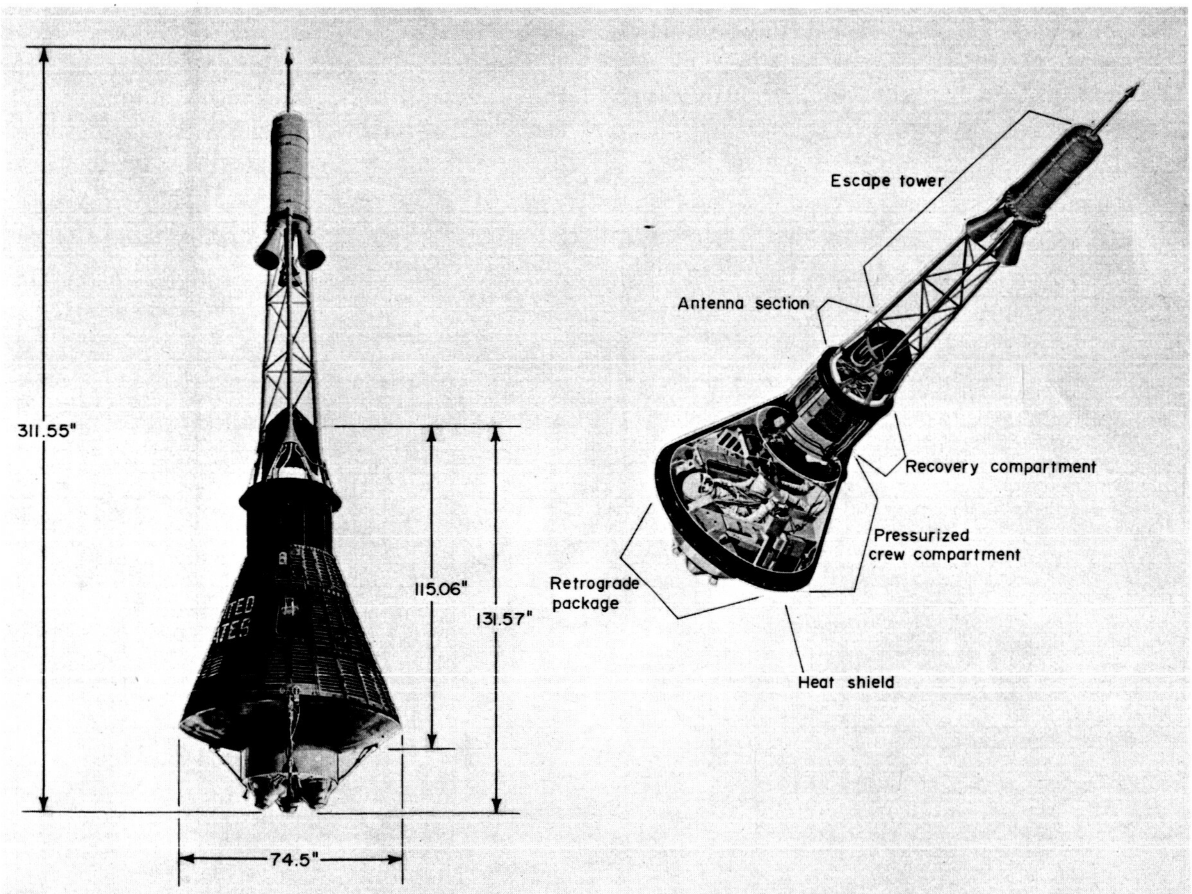

FIGURE 1–1.—General view of spacecraft.

hardware items would be proven in those environments to which they would be subject in both normal and emergency conditions associated with attainment of the planned mission conditions. One qualification flight test was planned with the use of the Little Joe launch vehicle. This test was planned to qualify the operation of the production spacecraft in a spacecraft-abort situation at the combination of dynamic pressure, Mach number, altitude, and flight-path angle that represented the most severe condition anticipated for the use of this system during an orbital launch. There were eight flight tests planned with the use of the Redstone launch vehicle. The first two were intended to be unmanned tests used to qualify the production spacecraft and to qualify the production-spacecraft launch-vehicle combination. The remaining six Mercury-Redstone flights were to be used to train and qualify Mercury astronauts for later orbital flights. Two flight tests were planned in which the Jupiter launch vehicle was to be used. The first one of these was to be made to qualify the production spacecraft for those flight conditions which produced the greatest load factor during reentry. The second Jupiter powered flight was scheduled as a backup to the first. The qualification program for the production spacecraft also included plans for three flight tests using the Atlas launch vehicle and the remainder of the flights were expected to be used for manned orbital flight if the flight qualification achieved at the time so warranted.

This flight-test plan was developed and proposed in early 1959 as a test plan that represented a completely trouble-free preparation and flight-test program. According to this schedule, the first manned orbital flight could have occurred as early as April of 1960. This flight-test schedule represents planning that was done before experience was gained in the production of spacecraft flight hardware and, particularly important, before any experience had been gained in the preparation of space flight equipment for manned flight.

The planned flight test schedule (fig. 1–2) presents some missions that are shaded. This shading indicates that these particular missions were eliminated during the course of the program because the requirement either was not necessary or was satisfied by some other means. In addition, it should be noted that the objectives of some of the other missions were altered to fit the situation as the project advanced.

Actual Flight Test Schedules

The 25 major flight tests accomplished during the Mercury Project are shown in figure 1–3, in the order of their occurrence. Those flight-test missions which are marked with solid circles in-

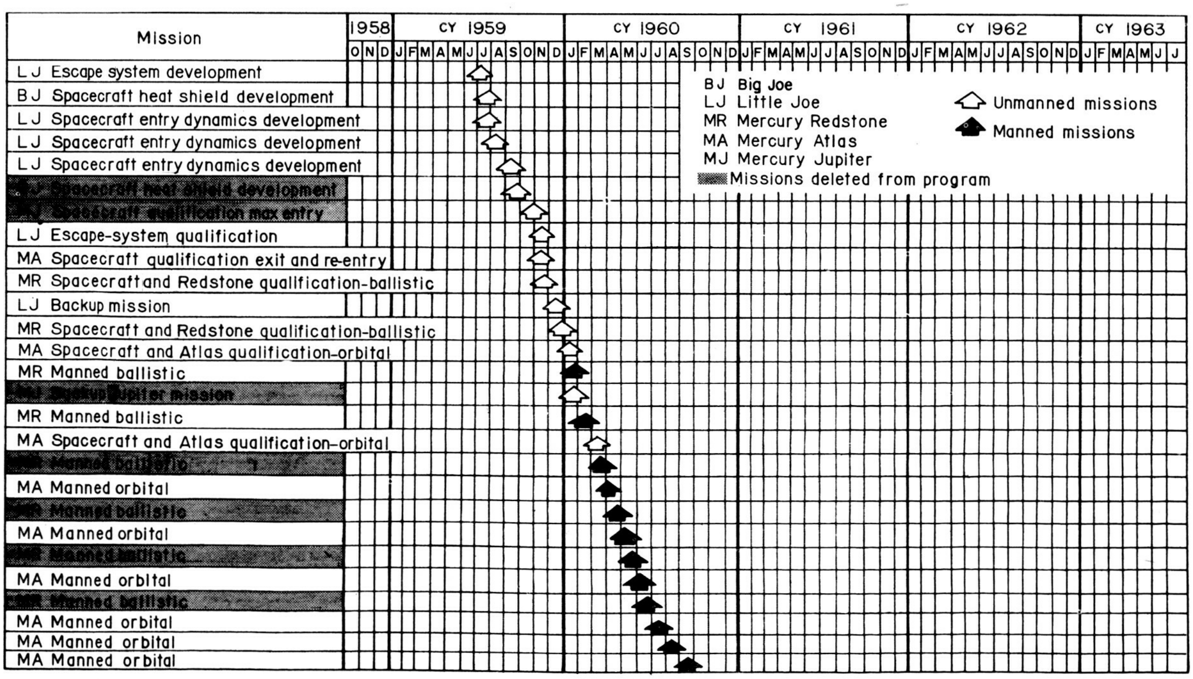

FIGURE 1–2.—Planned flight schedule as of January 1959.

dicate the missions that were added to this schedule as a result of lessons learned during some of the preceding flight tests or because of extensions to the basic mission objectives as in the case of the last two missions, MA–8 and MA–9.

Little Joe 1.—The flight test program was initiated with the Little Joe 1 research-and-development mission that was scheduled for July of 1959. The actual launch attempt came in the following month, on August 21, at the NASA launch site, Wallops Station, Va. A nearly catastrophic failure occurred at a time late in the launch countdown as the vehicle battery-power supply was being charged. At this time, the escape-rocket sequence was unintentionally initiated and the spacecraft was separated from the launch vehicle and propelled into the air as in a pad-abort sequence. The escape sequence was accomplished correctly, though initiated by a fault. The tower was jettisoned properly, the drogue parachute was deployed as it should have been, but the main parachute deployment circuitry was not activated because of a lack of sufficient electrical power. The spacecraft was destroyed on impact with the water. The cause of the failure was determined by detailed analyses to be a "backdoor" circuit which permitted the launch-escape system to be activated when a given potential had been supplied to the battery by ground charging equipment. The launch vehicle, though fully loaded with six solid-propellant rocket motors, was left undamaged on the launcher.

Big Joe 1.—Spacecraft checkout for the launch of Big Joe 1 was accomplished at the Cape Canaveral launch site starting in June of 1959. The primary purpose of the flight was to investigate the performance of the ablation heat shield during reentry, as well as to investigate spacecraft reentry dynamics with an instrumented boilerplate spacecraft. Other items that were planned for investigation on this flight were afterbody heating for both the exit and reentry phases of flight, drogue and main parachute deployment, dynamics of the spacecraft system with an automatic control system in operation, flight loads, and water-landing loads. Recovery aids, such as SOFAR bombs, radio beacons, flashing light, and dye markers, had been incorporated. This spacecraft was not equipped with an escape system. The mission was accomplished on September 9, 1959. Because of the failure of the Atlas booster engines to separate, the planned trajectory was not followed exactly, but the conditions which were achieved provided a satisfactory fulfillment of the test objectives. The landing point of the spacecraft was about 1,300 nautical miles from the lift-off point, which was about 500

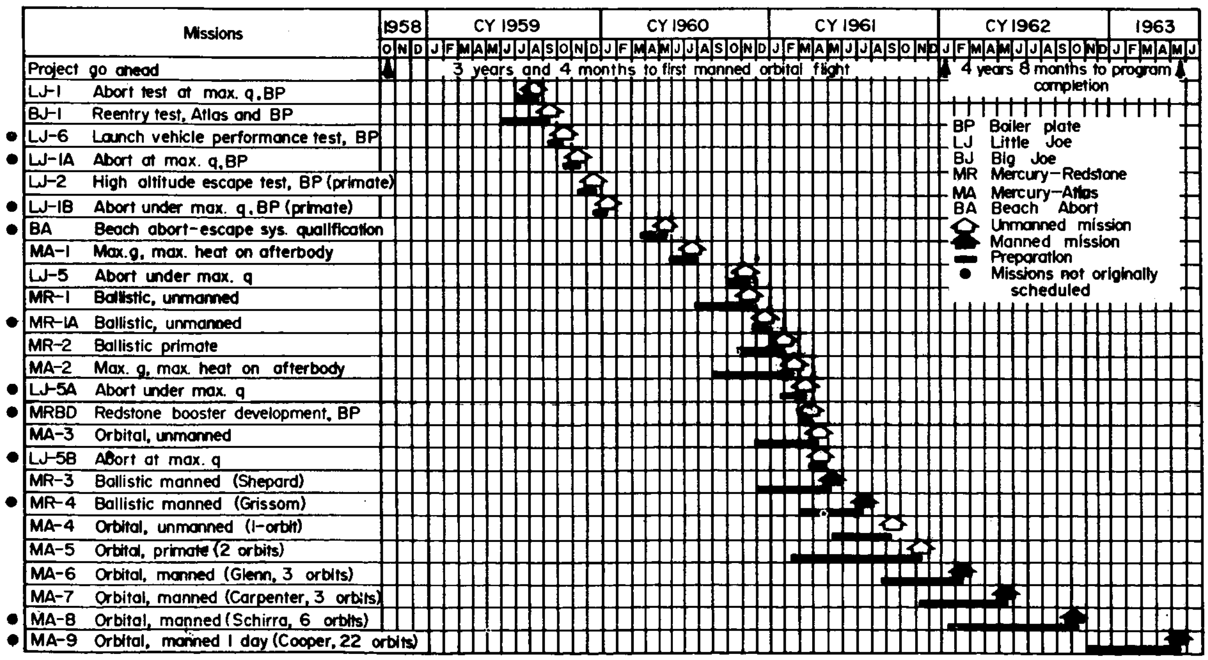

FIGURE 1–3.—Actual flight schedule.

nautical miles short of the intended landing point. Even so, the recovery team retrieved the spacecraft about 7 hours after landing.

Data from instrumentation and results of inspection of the spacecraft showed that the heat-protection method planned for the production spacecraft was satisfactory for a normal reentry from the planned orbit. On the basis of these results, the backup Big Joe mission was cancelled.

Little Joe 6.—The Little Joe 6 mission was successfully accomplished on October 4, 1959, from the Wallops Station launch site and demonstrated a qualification of the launch vehicle by successfully flying with staged propulsion on a trajectory which gave structural and aerodynamic loads in excess of those expected to be encountered on the other planned Little Joe missions. In addition, a method devised for correcting the launcher settings for wind effects, the performance of the booster command thrust termination system, and the launch operation were checked out satisfactorily. Two minor modifications were made to the Little Joe vehicle as a result of this flight to protect the second-stage rocket motor and the launch vehicle base from heat radiated from the thrusting motors.

Little Joe 1A.—Little Joe 1A was launched on November 4, 1959, from the Wallops Station launch site, as a repeat of the Little Joe 1 mission. The inflight abort was made, but the first-order test objective was not accomplished because of the slow ignition of the escape rocket motor. This slow ignition delayed spacecraft-launch-vehicle separation until the vehicle had passed through the desired test region. All second-order test objectives were met during the flight and the spacecraft was successfully recovered and returned to the launch site. All other Mercury hardware used in this test, principally the major parts of the escape and landing systems, performed satisfactorily.

Little Joe 2.—The Little Joe 2 mission, which was intended to validate the proper operation of the spacecraft for a high altitude abort, was accomplished on December 4, 1959, from the Wallops Station launch site. The abort sequence was initiated at an altitude of almost 100,000 feet and approximated a possible set of abort conditions that could be encountered during a Mercury-Atlas exit flight to orbit. In addition to the first-order objectives, the spacecraft reentry dynamics behavior without a control system was found to be satisfactory. The spacecraft dynamic stability on descent through the atmosphere was found to be as expected. Additional information was obtained on the operation of the Mercury parachute, the Mercury spacecraft flotation characteristics, and the operational requirements of spacecraft recovery by surface vessels. A monkey was a passenger on this mission; both the monkey and the spacecraft were recovered in satisfactory condition at the end of the mission.

Little Joe 1B.—The Little Joe 1B mission was successfully accomplished on January 21, 1960, from the Wallops Station launch site. This mission had been added to the flight schedule because of the failures of Little Joe 1 and Little Joe 1A to meet the test objectives. On this mission, all test objectives were successfully met, with the accomplishment of an abort at the conditions described for Little Joe 1A. This spacecraft also had a monkey as a passenger. Both the monkey and the spacecraft were recovered satisfactorily at the end of the mission.

Beach Abort 1.—Mission Beach Abort 1 (BA-1) was accomplished on May 9, 1960, from the Wallops Station launch site and marked the first time that a production spacecraft underwent a major qualification flight test. Production spacecraft 1 was a reasonably complete spacecraft and contained many systems that later spacecraft would be equipped with. It was launched on an abort sequence from a launcher on the ground. The escape-rocket motor provided the impulse as it would on an escape from a launch vehicle while still on the pad. The test was successful and the feasibility of an abort from a pad was adequately demonstrated. Though the mission was successful, certain modifications to spacecraft equipment were found to be desirable after the performance of these systems was analyzed. Although separation of the escape tower was accomplished, it was not considered satisfactory because of the small separation distance provided. This resulted in the redesign of the escape-system jettison rocket-motor nozzles. The single nozzle was replaced by a tri-nozzle assembly to prevent rocket-motor performance loss by impingement of the exhaust plumes on the escape-tower structure. This modification proved to

be satisfactory and was retained for the remainder of the Mercury program. Another anomaly was the poor performance of the spacecraft telemetry transmitters. Investigation showed that the cause of this poor performance was a reversal of the cabling of the transmitter systems; thus, for the first time in the program, inadvertent cross connection of connectors had been deleted.

Mercury-Atlas 1.—The Mercury-Atlas 1 (MA–1) vehicle was launched from the Cape Canaveral test site on July 29, 1960. The primary purpose of the MA–1 flight was to test the structural integrity of a production Mercury spacecraft and its heat-protection elements during reentry from an exit abort condition that would provide the maximum heating rate on the afterbody of the spacecraft. The spacecraft involved was production item 4 and was equipped with only those systems which were necessary for the mission. An escape system was not provided for this spacecraft. The mission failed about 60 seconds after lift-off. The spacecraft and launch vehicle impacted in the water east of the launch complex. Because of this failure, an intensive investigation into the probable causes was undertaken. As a result of this investigation modifications were made to the interface area between the launch vehicle and the spacecraft to increase the structural stiffness. This inflight failure and subsequent intensive investigation resulted in a considerable delay in the launch schedule and the next Mercury-Atlas launch was not accomplished until almost 7 months later.

Little Joe 5.—The Little Joe 5 vehicle was launched on November 8, 1960, from the Wallops Station launch site. The test was intended to qualify a production spacecraft. It was a complete specification spacecraft at that time with the following exceptions: the landing-bag system was not incorporated; the attitude stabilization and control system was not fully operational, but was installed and used water to simulate the control system fuel; and certain components of the communications system not essential to the mission were omitted. The mission failed during flight when the escape-rocket motor was ignited before the spacecraft was released from the launch vehicle. The spacecraft remained attached to the launch vehicle until impact and was destroyed. The exact cause of the failure could not be determined because of the condition of the spacecraft components when recovered from the ocean floor and because of the lack of detailed flight measurements. The results of the analyses attributed the failure to components of the sequential system, but the cause could not be isolated. The sequential systems of spacecraft 2 and 6 were modified to preclude the possibility of a single erroneous signal igniting the escape-rocket motor.

Mercury-Redstone 1 and 1A.—The Mercury-Redstone 1 (MR–1), which was to provide qualification of a nearly complete production spacecraft number 2, in flight with a Mercury-Redstone launch vehicle, was attempted on November 21, 1960, at the Cape Canaveral launch site. The mission was not successful. At lift-off, the launch-vehicle engine was shut down and the launch vehicle settled back on the launcher after vertical motion of only a few inches. The spacecraft also received the shutdown signal and its systems reacted accordingly. The escape-rocket system was jettisoned and the entire spacecraft landing system operated as it had been designed. Analyses of the cause of malfunction showed the problem to have been caused by failure of two ground umbilicals to separate from the launch vehicle in the proper sequence. In the wrong sequence, one umbilical provided an electrical path from launch-vehicle power through blockhouse ground and the launch-vehicle engine cut-off relay coil to launch-vehicle ground that initiated the cut-off signal. Except for loss of expendable items on the spacecraft, such as the escape system and the parachutes and the peroxide, the spacecraft was in flight condition. The launch vehicle was slightly damaged in the aft section by recontact with the launcher The spacecraft and launch vehicle were demated. The launch vehicle was replaced by another Mercury-Redstone launch vehicle, and the spacecraft was again prepared for its mission. Modifications included a long ground strap that was placed between the launch vehicle and the launcher to maintain electrical ground until umbilicals had been separated. The refurbished spacecraft and new Mercury-Redstone launch vehicle were launched successfully as mission MR–1A on December 19, 1960. At this time, all test objectives were met. All major spacecraft systems performed well

throughout the flight. The launch-vehicle performance was normal except for a higher than nominal cut-off velocity. The only effects of this anomaly were to increase the range, maximum altitude, and maximum acceleration during reentry. The spacecraft was picked up by a helicopter 15 minutes after landing and was delivered back to the launch site on the morning after the launch.

Mercury–Redstone 2.—The MR–2 mission was accomplished on January 31, 1961, from the Cape Canaveral test site with a chimpanzee as a passenger. Production spacecraft 5 was used. The mission was successful and the majority of the test objectives were met. Analyses of launch-vehicle data obtained during the flight revealed that launch-vehicle propellant depletion occurred before the velocity cut-off system was armed and before the thrust chamber abort switch was disarmed. This combination of events resulted in an abort signal being transmitted to the spacecraft from the launch vehicle. The spacecraft reacted correctly to the abort signal and an abort sequence was properly made. The greater than normal launch-vehicle velocity combined with the velocity increment obtained unexpectedly from the escape-rocket motor produced a flight path that resulted in a landing point about 110 nautical miles farther downrange than the planned landing point. This extra range, of course, was the prime factor in the 2 hours and 56 minutes that it took to locate and recover the spacecraft. The chimpanzee was recovered in good condition, even though the flight had been more severe than planned. By the time the spacecraft was recovered, it had nearly filled with water. Some small holes had been punctured in the lower pressure bulkhead at landing. Also, the heat-shield retaining system was fatigued by the action of the water and resulted in loss of the heat shield. Another anomaly that occurred during the flight was the opening of the spacecraft cabin inflow valve during ascent, which prevented the environmental control system from maintaining pressure at the design level. Because the pressure dropped below the design level, the emergency environmental system was exercised, and it performed satisfactorily. From the experiences of this flight, a number of modifications were made to the spacecraft systems to avoid recurrence of the malfunctioning items. These modifications included the following:

(1) An additional fiber glass bulkhead was installed between the heat shield and the large pressure bulkhead to protect the bulkhead during landing, and items in the large pressure bulkhead area that could be driven "dagger-like" through the larger pressure bulkhead during the landing were removed or reoriented.

(2) The heat-shield retention system was improved with the addition of a number of cables and cable-retention devices. The modified heat-shield retention system was proved to be capable of retaining the heat shield to the spacecraft in rough seas for periods of up to 10 hours.

(3) Tolerances of the inflow valve detent system were changed to assure positive retention during periods of vibration.

Mercury–Atlas 2.—The Mercury–Atlas 2 vehicle was launched from the Cape Canaveral test site on February 21, 1961, to accomplish the objectives of the MA–1 mission. The space vehicle for this flight consisted of the sixth production spacecraft and Atlas launch vehicle No. 67–D. Several structural changes made in the spacecraft launch-vehicle interface area as a result of the failure of the preceding Mercury–Atlas missions were as follows:

(1) The adapter was stiffened.

(2) The clearance between the spacecraft retropackage and the launch-vehicle lox tank dome was increased.

(3) An 8-inch-wide stainless-steel band was fitted circumferentially around the upper end of the launch-vehicle lox tank.

(4) The lox-valve support structure was changed so that the valve was not attached to the adapter.

(5) Special instrumentation was installed in the spacecraft launch-vehicle interface area to measure loads, vibrations, and pressures.

The major test objective of the MA–2 mission was to demonstrate the integrity of the spacecraft structure, ablation shield, and afterbody shingles for the most severe reentry from the standpoint of load factor and afterbody temperature. The flight closely matched the desired trajectory, and the desired temperature and loading measurements were obtained. The spacecraft landed in the planned landing area and was recovered and placed aboard a recovery ship approximately 55 minutes after it was

launched. A preliminary evaluation of measured data and a detailed inspection of the recovered spacecraft indicated that all test objectives were satisfied and that the spacecraft structure and heat-protection elements were in excellent condition.

Little Joe 5A.—The Little Joe 5A mission was accomplished on March 18, 1961, from the Wallops Station launch site. This was an added mission, as a result of the failure of the Little Joe 5. For the Little Joe 5A mission, production spacecraft 14 and the sixth Little Joe launch vehicle to be flown were used. The spacecraft was a basic Mercury configuration with only those systems installed that were required for the mission. As during the Little Joe 5 mission early ignition of the escape-rocket motor occurred. The mission was unsuccessful. However, unlike the Little Joe 5 mission, a backup spacecraft separation system was initiated by ground command and successfully separated the spacecraft from the launch vehicle and released the tower. Because of the severe flight conditions existing at the time of parachute arming, both main and reserve parachutes were deployed simultaneously. They filled and enabled the spacecraft to make a safe landing. All other active systems operated properly except that the cabin pressure-relief valve failed to maintain the spacecraft cabin pressure because of a piece of safety wire found lodged in the seat. The spacecraft was recovered and returned to the launch area in good condition. Analysis of data from the spacecraft proved that the early ignition of the escape rocket motor was caused by structural deformation in the spacecraft-adapter interface area. This early ignition permitted separation sensing switches to falsely sense movement and give the signal for the remainder of the sequence. The corrections applied were to reduce air loading in the area by better fairing of the clamp-ring cover, by increasing the stiffness of the switch mounting and reference structures, and rerouting the electrical signals from these switches through a permissive network.

Mercury–Redstone–Booster Development.—The Mercury–Redstone–Booster Development (MR–BD) mission was made on March 24, 1961, from the Cape Canaveral launch site, with a Mercury-Redstone launch vehicle and the refurbished and ballasted Little Joe 1A research-and-development spacecraft. This flight was made as the result of the analyses of the performance of the launch vehicles on the Mercury-Redstone 1A and Mercury-Redstone 2 flights, which showed that there were some launch-vehicle problems that required correction and requalification. Most of these problems had to do with the overspeed performance that was attained during those missions. The flight was successful and analyses of the launch-vehicle data indicated that the launch-vehicle corrections were entirely satisfactory. No recovery of the spacecraft was attempted since it was used only as a payload of the proper size, shape, and weight, and no provisions were made to separate it from the launch vehicle during the mission.

Mercury–Atlas 3.—The Mercury–Atlas 3 (MA–3) mission was accomplished on April 25, 1961, from the Cape Canaveral test site. The planned flight, which was intended to orbit an unmanned production spacecraft once around the earth, was terminated about 40 seconds after lift-off by range-safety action when the launch vehicle failed to roll and pitch over into the flight azimuth. The spacecraft was aborted successfully as the result of the command signal and was quickly recovered. The spacecraft came through the abort maneuver with only minor damages. The performance of all spacecraft systems was generally satisfactory throughout the short flight. The spacecraft used on this mission was the eighth production unit. The launch vehicle, Atlas 100–D, had increased skin thickness in the forward end of the lox tank and had the abort sensing and implementation system installed for closed-loop operation. Analysis of records indicated that there was an electrical fault in the launch vehicle autopilot. Subsequent action resulted in closer examination of electrical components and connections.

Little Joe 5B.—The Little Joe 5B vehicle was launched on April 28, 1961, from the Wallops Station launch site. The vehicle was composed of Mercury production spacecraft 14A and the seventh Little Joe launch vehicle to be flown. The spacecraft, which had previously been used for the Little Joe 5A mission, had been refurbished with only those systems installed that were required for the mission. There was no landing bag and certain other

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nonessential systems were missing. It was the first spacecraft to be flight-tested with modified spacecraft-adapter clamp-ring limit-switch mountings and fairings. Also, the sequential system was modified to prevent the limit switches on the spacecraft-launch-vehicle clamp ring or the spacecraft-escape-tower clamp ring from closing any circuits which would ignite the escape rocket until the band separation bolts were fired. These changes in and around the spacecraft-launch-vehicle interface and in the sequential system were made as the result of the problems encountered in missions Little Joe 5 and Little Joe 5A. Because of a severe change in flight path as the result of the delayed ignition of one of the two main launch-vehicle rocket motors, the test was made at substantially more severe flight conditions than planned. The abort was planned to be initiated at a dynamic pressure of 990 lb/sq ft; instead the dynamic pressure had attained a value of about 1,920 lb/sq ft when the abort was initiated. However, the spacecraft escape system worked as planned and this test successfully demonstrated the structural integrity of the Mercury spacecraft. The spacecraft landed in the ocean after about 5 minutes of flight and was recovered and returned to the launch site in less than 30 minutes after launch. Analyses of the flight data and inspection of the spacecraft after the mission showed the spacecraft to be in good condition. An anomaly that showed up was the failure of two of the small spacecraft umbilicals to eject. Evidence indicated that these umbilicals failed to eject because of interference with the clamp-ring fairing after its release. This condition was corrected by changing the manner in which the fairing was supported on subsequent spacecraft. All test objectives were considered to have been met.

Mercury-Redstone 3.—The Mercury-Redstone 3 (MR–3) mission, the first manned space flight by the United States, was successfully accomplished on May 5, 1961, from the Cape Canaveral launch site. Astronaut Alan B. Shepard was the pilot. The space vehicle was composed of production spacecraft 7 and a Mercury-Redstone launch vehicle, which was essentially identical to the one used for the MR–BD launch-vehicle qualification mission. Analyses of the results of the mission showed that Astronaut Shepard satisfactorily performed his assigned tasks during all phases of the flight. Likewise, launch vehicle and spacecraft systems performed as planned. The spacecraft achieved an altitude of about 101 nautical miles and was in weightless flight for slightly over 5 minutes. Postflight examination of Astronaut Shepard and inspection of the spacecraft showed both to be in excellent condition. A helicopter pickup was made of the spacecraft after the pilot had made his egress from the side hatch of the spacecraft and had been hoisted aboard the helicopter. The pilot and the spacecraft were landed aboard an aircraft carrier 11 minutes after spacecraft landing, and the spacecraft was brought back to the launching site the morning after the flight.

Mercury-Redstone 4.—The Mercury-Redstone 4 (MR–4) flight was successfully made on July 21, 1961, from the Cape Canaveral launch site. Astronaut Virgil I. Grissom was the pilot. The space vehicle was made up of the 11th production spacecraft and a Mercury-Redstone launch vehicle essentially identical to the one used for MR–3 mission. The spacecraft on this mission was somewhat different from spacecraft 7, in that, for the first time, a manned spacecraft had a large top window, a side hatch to be opened by an explosive charge, and a modified instrument panel. The spacecraft achieved a maximum altitude of about 103 nautical miles, with a period of weightlessness of about 5 minutes. The flight was successful. After landing, premature and unexplained actuation of the spacecraft explosive side hatch resulted in an emergency situation in which the spacecraft was lost but the pilot was rescued from the surface of the water. Analyses of the data from the flight and debriefing by the astronaut indicated that, in general, the spacecraft systems performed as planned, except for the action of the spacecraft hatch. An intensive investigation of the hatch actuation resulted in a change in operational procedures. No fault was found in the explosive device.

Mercury–Atlas 4.—The Mercury–Atlas 4 (MA–4) vehicle was launched on September 13, 1961, from the Cape Canaveral launch site; it was a repeat of the MA–3 test and became the first Mercury spacecraft to be successfully inserted into orbit, returned, and recovered. Further objectives of this flight were to evaluate the

Mercury network and recovery operations concerned with orbital flight. The space vehicle for this flight was made up of Mercury–Atlas launch vehicle 88–D, with the same modifications as the launch vehicle used on the MA–3 mission, and the spacecraft which was used on the MA–3 mission. The spacecraft had been refurbished and designated 8A for this mission. This was a very complete spacecraft which included a man-simulator onboard to provide a load on the environment control system during orbital flight. Other differences between this spacecraft and spacecraft flown on subsequent missions were:

(1) The landing bag was not installed

(2) The spacecraft had small viewing windows rather than the large overhead window used on later spacecraft

(3) The spacecraft entrance hatch did not have the explosive-opening feature

(4) The instrument panel had a slightly different arrangement.

The launch vehicle provided the desired orbital path with a perigee of 85.9 nautical miles and an apogee of 123.3 nautical miles. The planned retromaneuver over the coast of California resulted in a landing in the Atlantic Ocean approximately 160 nautical miles east of Bermuda in the primary landing area. The spacecraft was recovered in excellent condition 1 hour and 22 minutes after landing. The mission achieved the desired objectives, even though certain anomalies showed up in systems behavior during the mission. None of the anomalies had serious consequence. The anomalies and action taken are as follows:

(1) A spacecraft inverter failed during the powered phases of flight. The cause was determined to be a vibration-sensitive component and found to be preventable by more precise and exacting acceptance tests.

(2) Some anomalies in the spacecraft scanner signals were detected during the mission. Steps were taken to modify the system to make it less sensitive to the effects of cold cloud layers.

(3) A leak developed in the spacecraft oxygen-supply system during the exit phase of the flight. The leak was small, and sufficient oxygen was available for the mission. Postflight analyses determined that the leak was caused by failure in a pressure reducer. The fault was corrected for subsequent missions.

(4) Some thrusters in the spacecraft automatic attitude control system had either reduced output or no output during the latter part of the orbit. Postflight analyses indicated that possibly the trouble was contamination of the metering orifices in some thruster assemblies.

Mercury–Atlas 5.—The Mercury–Atlas 5 (MA–5) mission was successfully made on November 29, 1961, from the Cape Canaveral launch site. A chimpanzee was the passenger on this flight. The mission was planned for three orbital passes and was to be the last qualification flight of the Mercury spacecraft and launch vehicle prior to a manned mission. The orbit was about as planned with perigee at 86.5 nautical miles and apogee at 128.0 nautical miles. Further objectives of this flight were to evaluate the Mercury network and recovery operations. In general, the spacecraft, launch-vehicle, and network systems functioned well during the mission until midway through the second pass when abnormal performance of the spacecraft attitude control system was detected and verified. This malfunction precluded the probably successful completion of the third pass because of the high rate of control fuel consumption. Accordingly, a retrofire command was transmitted to the spacecraft which resulted in it landing in the selected area at the end of the second pass. Recovery was completed 1 hour and 15 minutes after landing. The chimpanzee performed his assigned tasks without experiencing any deleterious effects during the mission and was recovered in excellent condition.

The primary anomaly during the mission was the control-system trouble which gave rise to increased fuel consumption by the attitude control system and which precipitated the abort of the mission at the end of the second orbital pass. The trouble was found to be a stopped-up metering orifice in one of the low-roll thrusters. Corrective action applied to subsequent missions included closer examinations for contamination in this system.

The spacecraft used for this mission was production spacecraft 9; and since it was the last qualification vehicle prior to the first manned orbital flight, it was intentionally made as nearly like the spacecraft for the manned mission as possible. This spacecraft included the large viewing window over the astronaut's head posi-

tion, the landing bag, a positive lock on the emergency-oxygen rate handle, an explosive-release type hatch, new provisions for cooling the inverters, and rate gyros modified to insure satisfactory operation in the vacuum condition. The launch vehicle, Atlas 93–D, was much like those launch vehicles used on the previous two Mercury–Atlas missions; however, some additional modifications were included on this vehicle. These modifications included a new lightweight telemetry system and a redundant path for the sustainer engine cut-off signal.

Mercury–Atlas 6.—Mercury–Atlas 6 (MA–6), the first manned orbital space flight made from the United States, was successfully made on February 20, 1962, from the Cape Canaveral test site. Astronaut John H. Glenn, Jr., was the pilot. The flight was planned for three orbital passes to evaluate the performance of the manned spacecraft systems and to evaluate the effects of space flight on the astronaut and to obtain the astronaut's evaluation of the operational suitability of his spacecraft and supporting systems. All mission objectives for this flight were accomplished. The astronaut's performance during all phases of the mission was excellent, and no deleterious effects of weightlessness were noted. In general, the spacecraft, launch vehicle, and network system functioned well during the mission. The main anomaly in spacecraft operation was the loss of thrust of two of the 1-pound thrusters which required the astronaut to control the spacecraft for a large part of the mission manually. The orbit was approximately as planned, with perigee at 86.9 nautical miles and apogee at 140.9 nautical miles. During the second and third passes, a false indication from a sensor indicated that the spacecraft heat shield might be unlocked. This indication caused considerable concern and real-time analyses resulted in the recommendation that the expended retropackage be retained on the spacecraft during reentry at the end of the third pass to hold the heat shield in place in the event it was unlatched. The presence of the retropackage during reentry had no detrimental effect on the motions of the spacecraft. Network operation, including telemetry reception, radar tracking, communications, command control, and computing, were excellent and permitted effective flight control during the mission. The spacecraft for this mission was production unit number 13 which was essentially the same as spacecraft 9 used in the MA–5 mission except for those differences required to accommodate the pilot, such as the couch, a personal equipment container, filters for the window, and some minor instrumentation and equipment modifications. The launch vehicle was Atlas 109–D. It differed from the MA–5 launch vehicle in only one major respect. For this launch vehicle, the insulation and its retaining bulkhead between the lox and fuel tank dome was removed when it was discovered that fuel had leaked into this insulation prior to launch. The spacecraft landed in the planned recovery area, close to one of the recovery ships. The spacecraft, with the astronaut inside, was recovered approximately 17 minutes after landing. The astronaut was in excellent shape.

Action to prevent recurrence of the anomalies encountered during the MA–6 mission included relocation of metering orifices and a change in screen material in the attitude control system thruster assemblies. Improved specifications, tighter quality control, and more conservative switch rigging and wiring procedures were applied to the sensors that indicated heat-shield release.

Mercury–Atlas 7.—The Mercury–Atlas 7 (MA–7) vehicle was launched on May 24, 1962, from the Cape Canaveral launch site. Astronaut M. Scott Carpenter was the pilot for this mission. The mission was planned for three orbital passes and was a continuation of the program to acquire additional operational experience and information for manned orbital space flight. All objectives of the mission were achieved. The spacecraft used for this flight was production unit number 18 which was very similar to the spacecraft 13 used on the MA–6 flight. Some of the more significant features and modifications applied to this spacecraft include: the SOFAR bomb and radar chaff were deleted, the earth-path and oxygen partial pressure indicators were deleted, the instrument observer camera was removed, provisions for a number of experiments and evaluation were added, a more complete temperature survey system was added, the astronaut's suit circuit constant-bleed orifice was deleted, the landing-

bag limit (heat-shield release) switches were rewired to prevent erroneous telemetry signals should one switch malfunction.

The launch vehicle, the Atlas 107–D, was similar to the previous Atlas launch vehicle except for a few minor changes, the major one of which was that for this mission, the fuel tank insulation bulkhead was retained. Launch-vehicle performance was satisfactory. A perigee of 86.8 nautical miles and an apogee of 145 nautical miles were the orbital parameters. During most of the flight, the spacecraft-system operation was satisfactory until, late in the third pass, the pilot noted that the spacecraft true attitude and indicated attitude in pitch were in disagreement. Because this control system problem was detected just before retrofire, no corrective action was possible and the astronaut was forced to provide manual attitude control, using the window and horizon as the attitude reference, for the retrofire maneuver. Retrofire occurred about 3 seconds late, and the optimum spacecraft attitudes were not maintained during retrofire. As a result, the spacecraft landed several hundred miles downrange of the planned landing point. Because of this, recovery of the astronaut was not accomplished until about 3 hours after landing. The spacecraft was retrieved later by a destroyer after about 6 hours in the water. Exact cause of the control system malfunction was not determined because the scanner circuitry suspected of causing the anomaly was lost when the antenna section was jettisoned during the landing phase. Changes in checkout procedures used in launch preparations were incorporated to prevent recurrence of this type of problem.

Mercury–Atlas 8.—The Mercury–Atlas 8 (MA–8) vehicle was launched from the Cape Canaveral launch site on October 3, 1962; Astronaut Walter M. Schirra, Jr., was the pilot. The MA–8 mission was planned for six orbital passes in order to acquire additional operational experience and human and systems performance information for extended manned orbital space flight. The objectives of the mission were successfully accomplished. The orbital parameters were as follows: perigee, 86.9 nautical miles; and apogee, 152.8 nautical miles. The space vehicle for this mission consisted of production spacecraft 16 and Atlas launch vehicle 113–D. The spacecraft was basically the same as spacecraft 18 utilized on the previous mission; however, a number of changes were made in the configuration to increase reliability, to save weight, to provide for experiments, and to conduct systems evaluations. The launch vehicle also had some changes as compared with the previous Mercury–Atlas launch vehicle. These changes include the following: the fuel tank insulation bulkhead was removed at the factory to be similar to the launch vehicle for the MA–6 mission, the two booster engine thrust chambers had baffled ejectors installed for improved combustion characteristics, and no holddown delay was programed between engine start and beginning of release sequence.

The pilot performed numerous experiments, observations, and systems evaluations during his mission. For the first time, extended periods of drifting flight were accomplished. Pilot adherence to the flight plan was excellent. Basic spacecraft systems, launch-vehicle systems, and ground-network systems performed well with only a few minor anomalies. The landing was made in the Pacific Ocean within sight of the primary recovery ship, and the spacecraft and pilot were recovered in about 40 minutes.

Mercury–Atlas 9.—The Mercury–Atlas 9 (MA–9) mission utilizing production spacecraft 20 and Atlas launch vehicle 130–D, was successfully accomplished on May 15 and 16, 1963, with Astronaut L. Gordon Cooper as the pilot. It was launched from the Cape Canaveral test site for a planned 22 orbital-pass mission. Launch-vehicle performance was excellent and a near perfect orbit was attained. The orbital parameters were as follows: perigee, 87.2 nautical miles; apogee, 144.2 nautical miles. For the first 18 orbital passes, the spacecraft systems performed as expected, and the pilot was able to adhere to the flight plan and perform his activities as planned. Up to that time, anomalies were limited to small nuisance-type problems. Beginning with the 19th orbital pass, the spacecraft systems problems began with actuation of the 0.05g warning light. Investigation of the occurrence of this warning light indicated that the automatic control system had become latched into the mode required for the reentry phase. Later, the alternating-current power supply for the control system failed to operate. These failures were analyzed by the pilot and the ground crew in real time

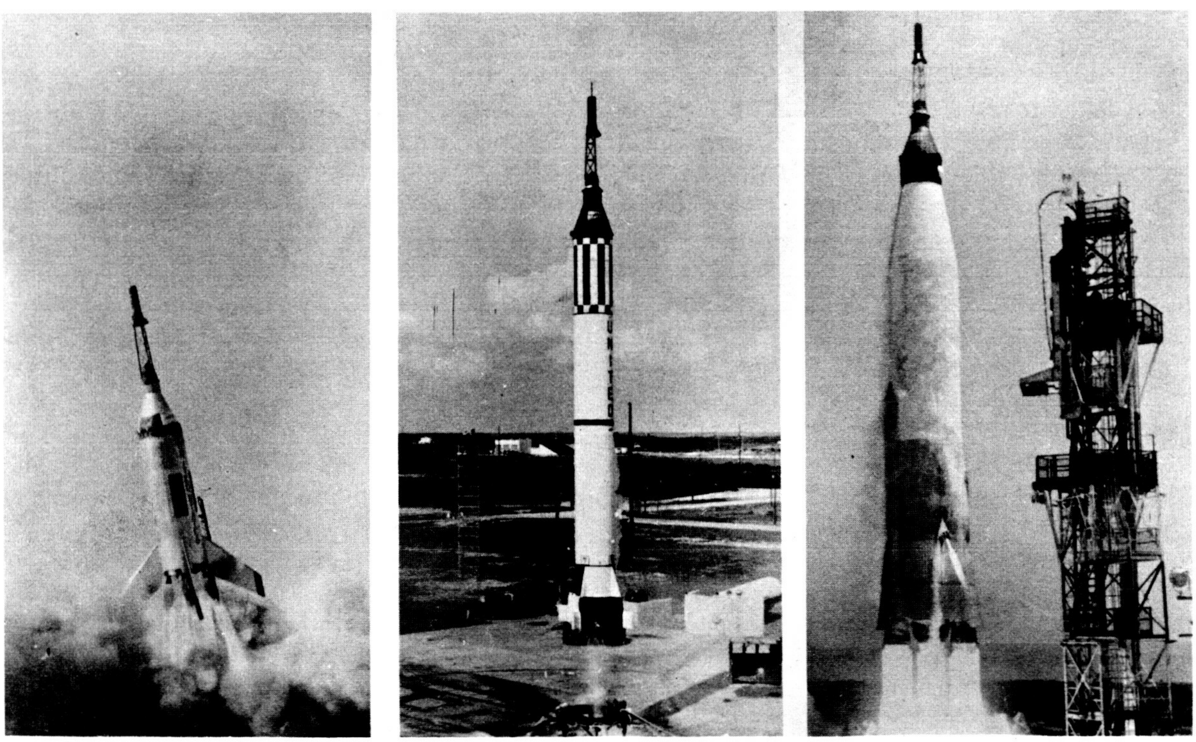
and it was determined that the pilot would have to make a manual retrofire and reentry. He performed these meneuvers with close precision and landed a short distance from the prime recovery ship in the Pacific. The pilot and the spacecraft were recovered and hoisted aboard the carrier only 40 minutes after landing. More detailed results of this mission are contained in other papers in this document.

Lift-off photographs of the three types of Mercury space vehicles are shown in figure 1–4.

PERFORMANCE

An examination of the history of the major flight tests, presented in figure 1–3, will show that the basic objectives of the Mercury Project were achieved 3⅓ years after official project approval, with the completion of Astronaut John Glenn's successful orbital flight on February 20, 1962. Subsequently, Astronaut Carpenter completed a similar mission. Then, Astronauts Schirra and Cooper completed orbital missions of increased duration to provide additional information about man's performance capabilities and functional characteristics in the space environment. In addition, increasing numbers of special experiments, observations, and evaluations performed during these missions by the pilots as their capabilities were utilized have provided our scientific and technical communities with much new information. It is emphasized that goals beyond those originally established were achieved in a period of 4⅔ years after the beginning of the project with complete pilot safety and without change to the basic concepts that were used to establish the feasibility of the Mercury Project.

In early 1959, immediately after project go-ahead, the first manned orbital flight was scheduled to occur as early as April 1960, or 22 months before the event actually took place (see fig. 1–5). This difference was caused by an accumulation of events which included delays in production spacecraft deliveries, difficulties experienced in the preparations for flight, and by the effects of the problem areas that were detected during the development and early qualification flight tests. The primary problem areas included those which were associated with the spacecraft–launch-vehicle struc-



Little Joe　　Redstone　　Atlas

FIGURE 1–4.—Lift-off photograph of the three types of Mercury space vehicles.

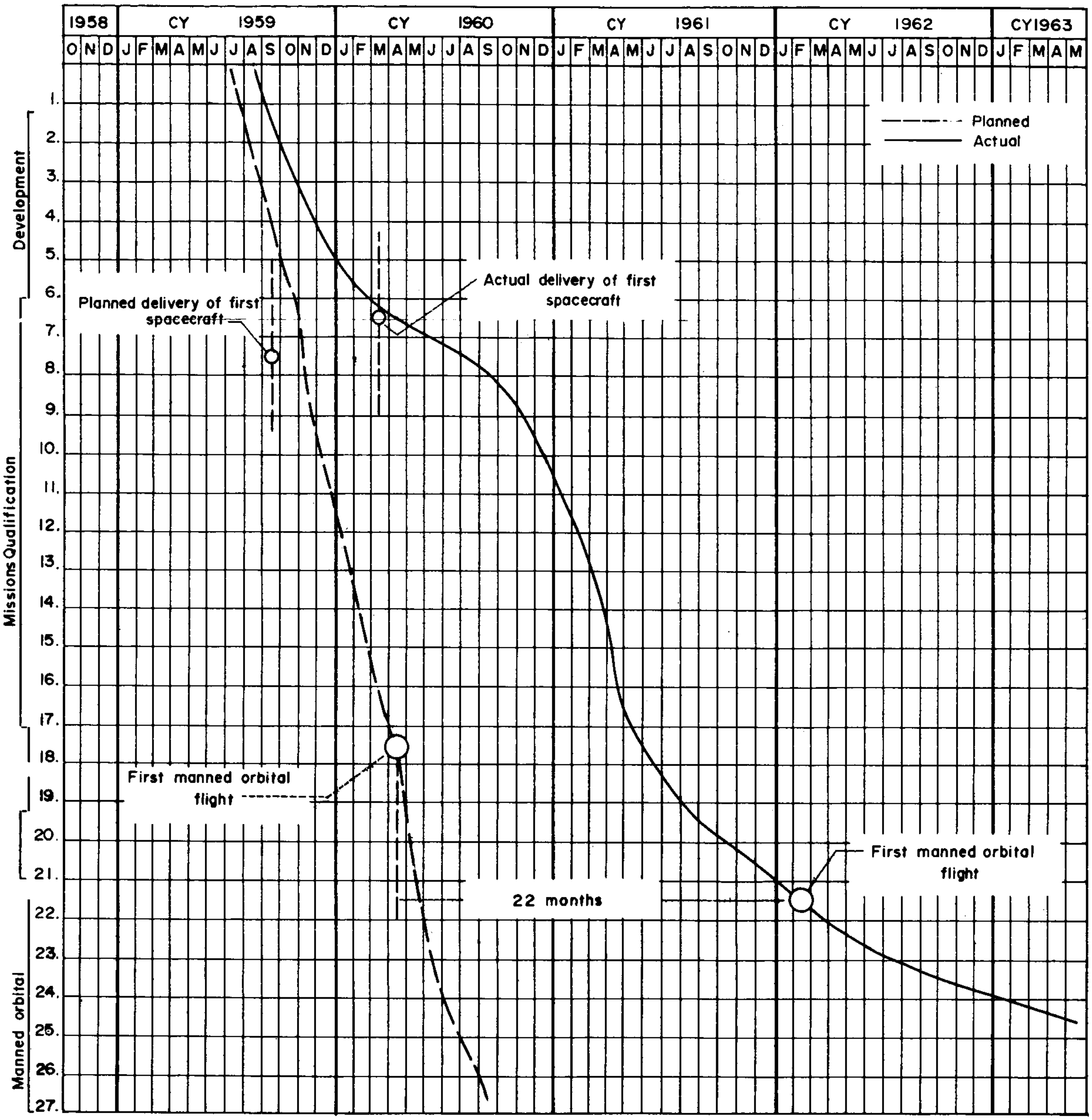


FIGURE 1-5.—Comparison of planned and actual flight schedules.

tural interface on the MA–1 mission, spacecraft sequential-system sensors on Little Joe missions 5 and 5A, launch-vehicle umbilical-release sequence on the MR–1 mission, launch-vehicle propulsion system on MR–2, and launch-vehicle control system on MA–3.

The applicability of these statements can be illustrated by reference line representations of the planned and actual schedules that are compared in figure 1–5. This comparison shows that the flight-test program was intiated about 1 month late. Missions through the development phase and those missions accomplished through most of the qualification phase were accomplished at about the planned rates. The major deviations occurred in 1960 when production spacecraft deliveries were later and when launch preparation took longer than planned. The planned schedule allowed for about a 4-week prelaunch preparation period at the launch site. Actual preparation time averaged about six times the estimated amount. Some of the additional required preparation time was compensated for by concurrent prepa-

ration of several spacecraft. Also, some significant problems were encountered during the early qualification missions which caused delays in the schedule by requiring additional missions to accomplish the objectives. These delays were accumulative and were not reduced during the life of the project. The delays that occurred later in the project resulted from deliberate efforts to insure that the preparation for the manned flights was complete and accurate and, still later, from changes made to increase the spacecraft capabilities.

Figure 1–3 shows that 25 flight tests were made in the 45-month period between the first mission and the end of the project, for an average of about one flight test in each 2-month period. This is a very rapid pace when the development and qualification nature of the program is considered. Even so, the average rate was low when compared with the rate that was maintained during the last part of 1960 and the early part of 1961 when five spacecraft were in preparation at once and the launchings occurred more frequently than once a month. It should also be noted that, during the period of high launch rate, preparations were accomplished at two widely separated sites, Cape Canaveral, Fla., and Wallops Station, Va.

While the flight missions were the significant outward signs of the project activity that resulted from the total effort, it was the behind-the-scenes activities that made the missions possible. The contents of figure 1–6 show the concurrent activity that existed in a number of the more significant areas of Project Mercury in order to reduce the time required to accomplish the objectives. The specific requirements in many areas were dependent upon the development being accomplished in the other areas. Thus, there was a continual iteration process carried on which resulted in a gradual refinement of requirements and completion of the work.

Management

Modes of Operation

Development of the management structure and operating mode to direct this complex and rapidly moving project began concurrently with the approval of the plans for a program of research and development leading to manned space flight which were presented to Dr. T. Keith Glennan, the first Administrator of the National Aeronautics and Space Administration (NASA) on October 7, 1958. The plans approved by Dr. Glennan on that date had been formulated by a joint National Advisory Committee for Aeronautics-Advanced Research Project Agency (NACA–ARPA) Committee, chaired by Dr. Robert R. Gilruth, at that time Assistant Director of Langley Research Center. The committee had been established during the summer of 1958 to outline a manned satellite program. With the approval of these plans by the Administrator of NASA, formerly the NACA, Dr. Gilruth was authorized to proceed with the accomplishment of the Manned Space Flight Project.

The Space Task Group (STG), later to become the Manned Spacecraft Center (MSC) was informally organized after this assignment to initiate action for the project accomplishment. The initial staff was comprised of 35 personnel from the Langley Research Center and 3 from the Lewis Research Center.

On November 5, 1958, the STG located at the Langley Research Center was formally established and reported directly to NASA Headquarters in Washington, D.C. At the same time, Dr. Gilruth was appointed head of the STG and project manager of the manned satellite program. By the end of November 1958 the manned satellite program was officially named Project Mercury.

The overall management of the program was the responsibility of NASA Headquarters, with project management the responsibility of the STG. It was recognized from the beginning that this had to be a joint effort of all concerned, and as such, the best knowledge and experience as related to all phases of the program and the cooperation of all personnel was required if success was to be achieved. It was also recognized that it was an extremely complex program that would probably involve more elements of government and industry than any development program before undertaken. Because of this complexity and involvement of so many elements, management was faced with an extremely challenging task of establishing an overall operating plan that would best fit the program and permit accomplishment of all objectives at the earliest possible date. To achieve

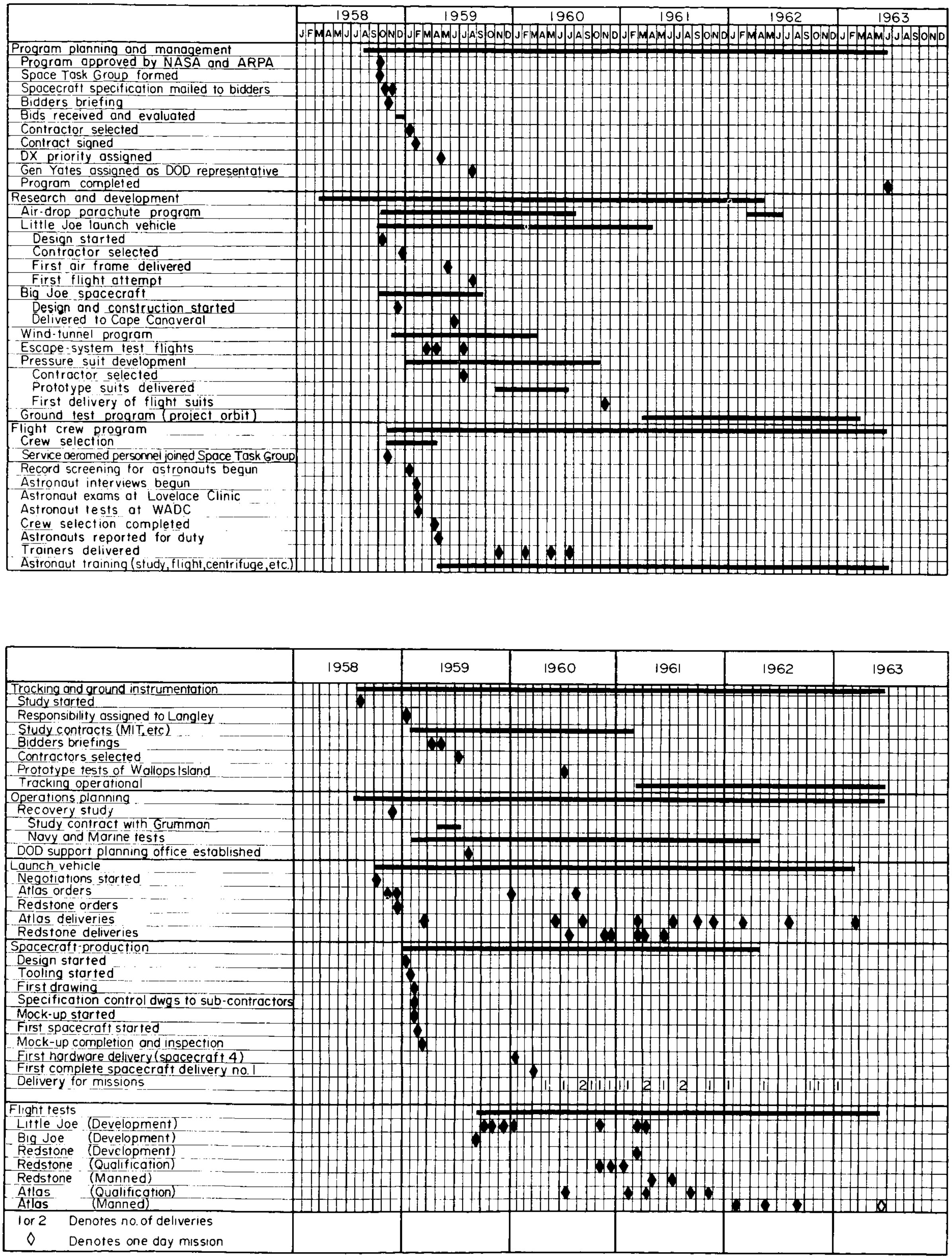


FIGURE 1-6.—Areas of primary activity during Project Mercury.

this task a general working arrangement was established as shown in figure 1-7. This figure illustrates in a very simplified format, the general plan used.

The arrangement was basically comprised of three working levels. The first level established the overall goals and objectives as well as the basic ground rules and the means for their accomplishment. The next level was responsible for establishing technical requirements and exercising detailed management. The detailed management was performed at this level and provided the approval and authorizing interface with all elements supporting the project. The bond of mutual purpose established here provided the direction and force necessary to carry the project forward. This same bond was evident in the groups or teams, in the third level of effort, set up to carry out the detailed implementation and, where necessary, further define the requirements. This level consisted of teams comprised of personnel from all necessary elements with responsibility for the assigned task and most knowledgeable in the area for which the group was responsible. These third level teams were established as required to investigate and define detailed technical requirements and insofar as possible to make the arrangements to implement their accomplishment. The team continued to function until all details of a particular technical requirement were worked out to the satisfaction of those concerned. As the tasks assigned to a particular team were completed, that team was phased out. New teams were established to meet new requirements which evolved and requirements of various phases as the project progressed.

An example of this working arrangement with a general explanation of how it worked is shown in figure 1-8. This example shows the arrangement used to procure and develop the Atlas launch vehicle for manned flight. To accomplish this, procurement agreements and overall policy were established between the U.S.

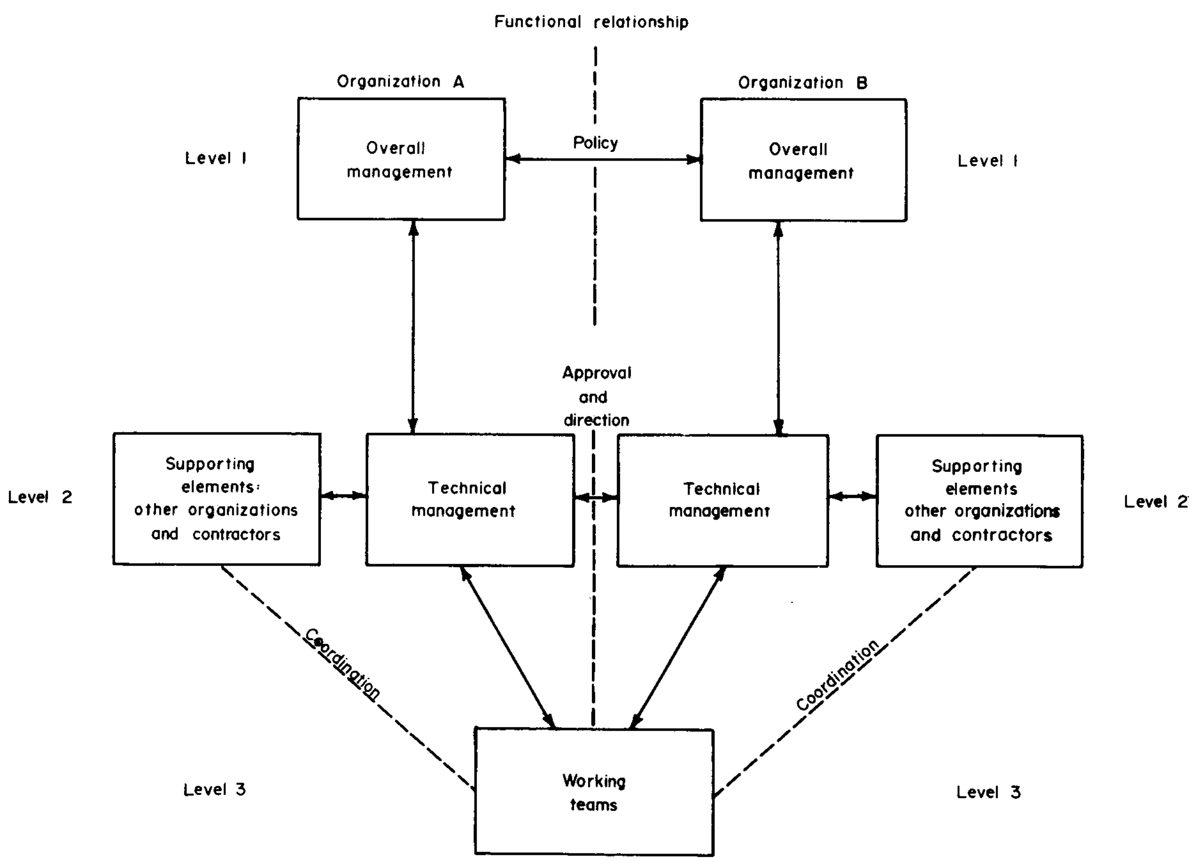


FIGURE 1-7.—Typical management arrangement.

Air Force Ballistic Missile Division of the Department of Defense and the NASA Headquarters. Working within the framework of these agreements the Atlas Weapons Systems Command of the U.S. Air Force and the NASA STG formulated the basic technical requirements necessary to adapt the Atlas for use in the program. Working teams consisting of specialists from the STG and the Atlas Weapons Systems Command were established to define the detail requirements and initiate the necessary action for their implementation. This implementation could be direct for cases in which the team had the authority or the recommendation for implementation could be forwarded to the necessary level of authority. In any case, the next higher level could alter the decisions of the lower level if developments required. This arrangement also provided a "closed-loop" management structure, thus assuring positive means of communication and proper technical directions. Frequently, specialists from the contractors and other supporting elements were included in the teams to assemble the best available talent to solve the problem. Quite often, tasks involving considerable effort were assigned directly to individual team members by the chairman of the group for implementation.

The same general arrangement was employed between NASA elements in accomplishing major tasks, such as establishing the Worldwide Tracking Network, as illustrated in figure 1-9. In addition to the many overall arrangements that had to be made in establishing the Worldwide Tracking Network, such as agreements with foreign governments, working through the State Department, regarding the location and operation of ground stations in their territory, the task of providing the hardware and facilities that made up the ground stations represented a major task that was primarily the responsibility of the STG and the Langley Research Center. This example covers the means by which the basic technical requirements and hardware needs of the ground stations were accomplished through the combined efforts of the STG and Langley. The Langley Research Center was responsible for the procurement and establishment of the network, with the basic flight monitoring and control requirements being the responsibility of the STG. The overall agreements regarding the implementation of this effort were established at the Director-Project Manager level with the basic technical requirements being defined at the level of the cognizant divisions. After the basic requirements were presented to the Langley Re-

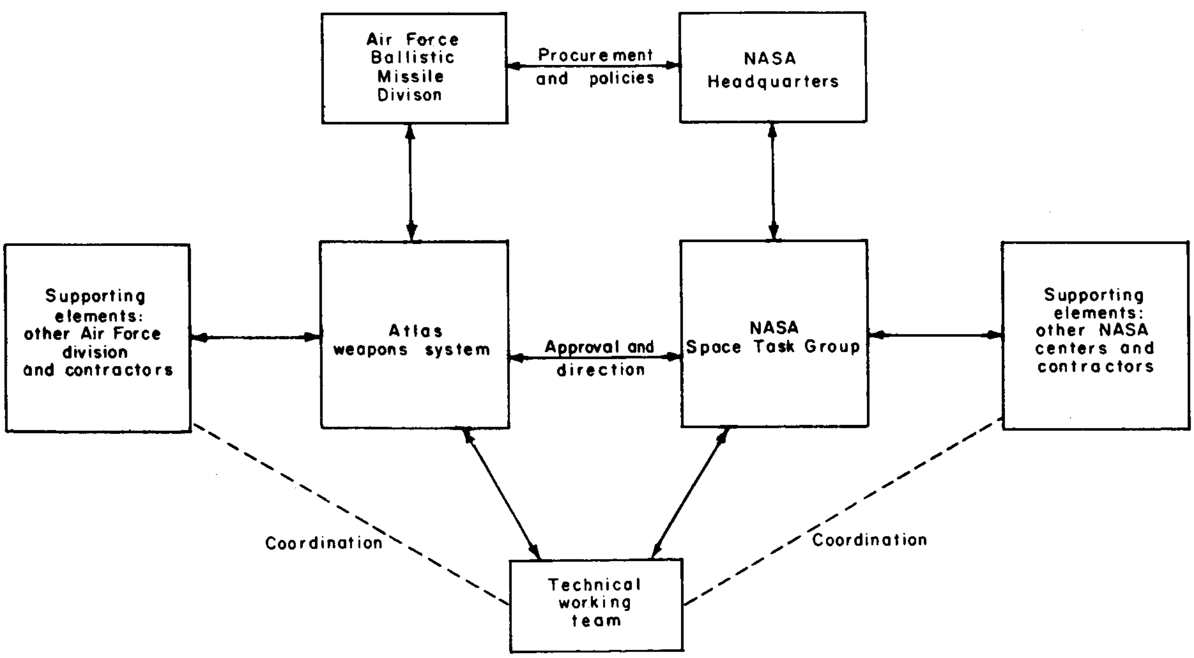


FIGURE 1-8.—Management arrangement used to procure, develop, and prepare the Atlas launch vehicle for manned flight.

search Center, teams were established to discuss and resolve the detail technical requirements of the network. For example, a team was assigned the task of establishing the communications and tracking requirements and resolving the type of equipment to be used on the spacecraft and the detail design characteristics of this equipment. They then had to determine if suitable receiving equipment for the ground stations was available or if it had to be developed. This involved coordinating overall requirements given to both the Langley Research Center's ground station contractors and the STG's spacecraft contractor to determine if the desired requirement could be achieved and if not, to determine an acceptable means of achieving the desired results. This points out only one detail area that this kind of group had to resolve; other areas such as location of the ground stations, frequencies of transmission, bandwidths, spacecraft antenna radiation patterns, and so on presented the same type of problems that had to be resolved. These efforts evolved into the Mercury Worldwide Tracking Network, the operation of which was the responsibility of the Goddard Space Flight Center (GSFC). Similar arrangements existed between the many elements necessary to develop the network and implement its operation.

To illustrate further this type working arrangement the identifications on figure 1–7 could be changed to represent those of the STG and the spacecraft contractor, McDonnell Aircraft Corporation (MAC). In this instance it was recognized by both parties that normal contractual procedures alone were insufficient to achieve the desired results within the scheduled time frame. Direct communication regarding technical requirements between the specialists of STG and MAC had to be the rule rather than the exception. Management agreements on the upper levels provided the framework whereby this could be accomplished and provided the management decisions for project direction. Frequently, the teams determined a course of action and proceeded without further delay, with verification documentation following through regular channels. The "closed-loop" built into the working arrangement provided the assurance that contractual and program requirements were met in all cases. Regular management reviews of hardware status and task achievement kept management abreast of the problem areas and afforded the opportunity for timely direction of effort to many specific problem areas. This mode of operation enhanced the rapidity with which a design change could be implemented or a course of action altered. This contributed to the timely conclusion of a project.

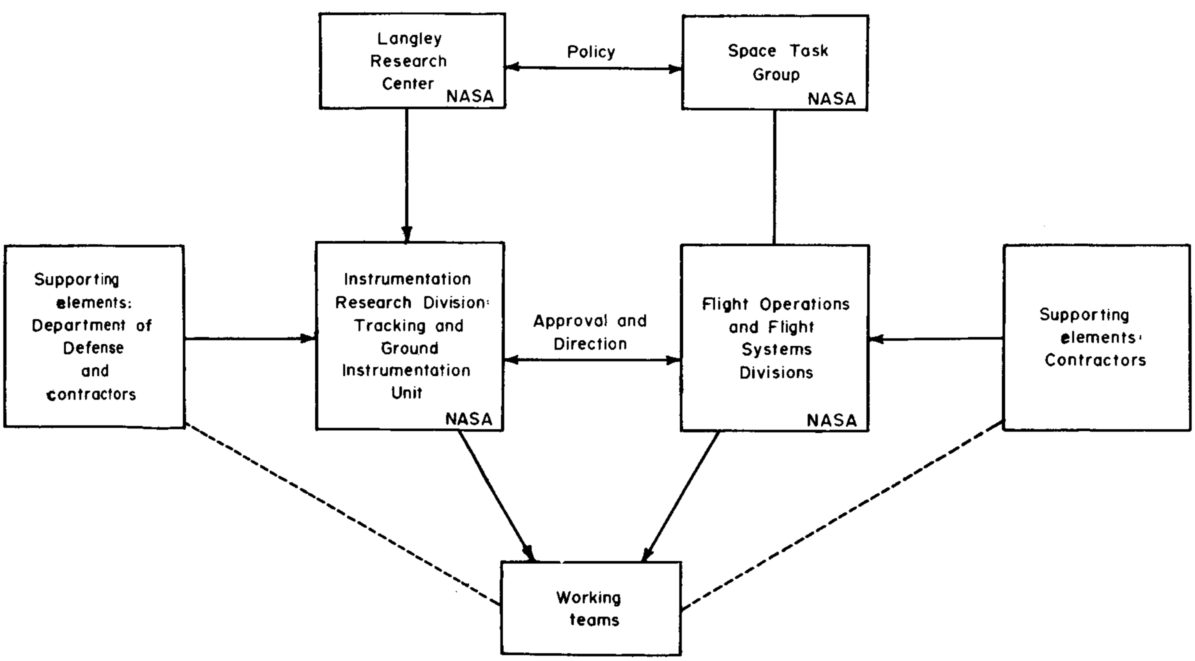


FIGURE 1–9.—Management arrangement used to establish the ground tracking organization.

The foregoing discussion is primarily concerned with the management techniques that existed with the external organizations, but the same type of procedure was commonly used within the organizational structure of the STG. As firm definition of the program emerged and final spacecraft design details were formalized, it became necessary to centralize the coordinating effort within the STG. To accomplish this, centralized review meetings were conducted on a regular basis to correlate all elements of the effort and ascertain that unified approaches and directions were maintained. These meetings were attended by cognizant personnel from within the STG and by personnel from other activities when required. The primary function of these meetings was to obtain the best inputs available for the technical management of the project and to control the engineering and design and thereby the configuration of the spacecraft. Information channeled into these meetings was dispersed directly to the responsible individuals within the STG, with assignments being made directly to the cognizant organization when action was required. Technical direction required as a result of action initiated at the coordination meetings, after thorough review as to need, cost, and effect on schedule, was issued to the applicable contractors. Meetings of this type provided fast response and accurate direction throughout the duration of the project. As the staff and project responsibilities increased, the support administrative functions performed by the Langley Research Center, such as Personnel, Procurement and Supply, and Budget and Finance Offices, were incorporated into the STG management organization.

The formation of the Mercury Field Operations Organization at Cape Canaveral marked the entry of Project Mercury into the operational phase of the program. In conjunction with this an Operations Director was appointed with complete responsibility and authority for flight preparation and mission operations. The Operations Director also served as the single point of contact for Department of Defense (DOD) activities supporting Project Mercury.

Although the general management modes of operation previously discussed were applied throughout the duration of the project, a different type functional organization was established for the specific purpose of conducting a space-flight mission. The organization covering the flight operations phase of the project was a line organization with elements from the government and contractor organizations involved in the operation reporting directly to the Operations Director. Figure 1–10 illustrates the manner in which these elements merged to form this functional line organization.

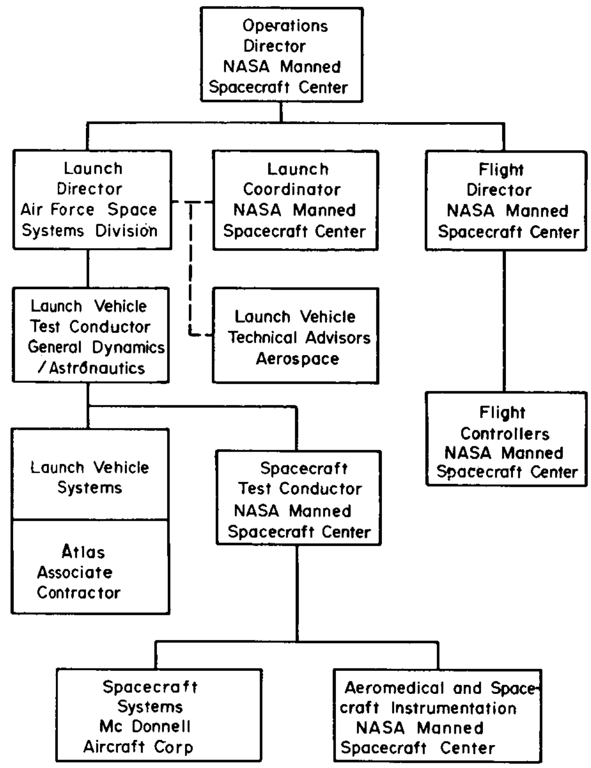


FIGURE 1–10.—Integrated functional organization for launch operations.

An organizational chart of this nature fails to show the unified effort, the cooperation, and the team work that was evident in every Mercury flight. All elements of government and industry supporting the project pulled together toward a common goal, with each individual striving to do his best. Without this spirit of cooperation and team work, the degree of success experienced in Project Mercury would not have been possible.

The success of Project Mercury demonstrated not only the reliability of the equipment but also the effectiveness of the management organization and the working arrangements with the various supporting elements throughout govern-

ment and industry. Efforts to assure that Project Mercury would meet its objectives evolved in the high level agreements that resulted in clear lines of authority and responsibility for technical direction.

With the increasing national effort in the field of space exploration, additional manned space projects were assigned to the STG. Because of the increased emphasis and scope of the manned spaceflight effort, the MSC was established in November 1961 from the nucleus provided by the STG. Soon after the MSC was established, the Mercury Project Office was created and assigned the responsibility and authority for detailed management and technical direction of the project, working with the support of other MSC units in areas in which they had cognizance or had specific specialties needed to achieve project objectives. The MSC organization existing at the end of the project is shown in figure 1-11. The Mercury Project Office provided the project management to the conclusion of the project and used the same general management method established early in the program.

Tools

A reporting system was required by management to control the fast-moving project so that effective and timely decisions could be made. Various methods used by management to accomplish this included reports, schedules, cost control, and later, program evaluation and review technique (PERT) in addition to the technical reviews previously mentioned.

Many types of technical reports were prepared for management in order to keep it abreast of progress and problems. These reports were concise and factual status reports issued daily, weekly, monthly, and quarterly to highlight progress or lack of progress without conjecture. Obviously, close to the launch date, the daily reports became the most important. Another valuable report was the one prepared after the completion of each mission. These were prepared expeditiously to present analyses of the performance of all the systems involved in the mission, from the lowest elements through operational recovery techniques. The results of these analyses were used immediately after a mission to form the basis for corrective action that often influenced the hardware on the very next mission. These results were issued in formal report formats that contained detailed descriptions of the mission and equipment, performance analyses, result of investigations of anomalies, and much of the data. The reporting effort became greater as the complexity and duration of the missions increased, and larger reports and longer preparation times resulted. However, in most cases, the reports were printed for distribution within 30 days after the mission. The report of the MA-9 mission, for example, contained more than 1,000 pages of information.

Innumerable documents were generated covering all aspects of the program during the life of Project Mercury so that management as well as the individual elements could have overall knowledge of project details and progress. These documents were prepared by all elements participating in the program and included such general types as drawings, familiarization manuals, specifications, operational procedures, test procedures, qualification status, test results, mission results, reports on knowledge gained and status reports of all kinds. It is estimated that at least 30 formal documents, excluding drawings, engineering change orders, and so forth, were issued during the course of the project. A partial listing of the types of documentation used during the program is included in appendix A.

Overall schedule control was accomplished by the use of a Master Working Schedule which indicated major milestones, such as spacecraft deliveries and checkout periods, launch-vehicle deliveries and checkout times, launch-complex cleanup and conversion, and tracking network status. Detailed bar-chart schedules were maintained in areas of direct concern, such as individual spacecraft at the manufacturer's plant, launch preparation of the spacecraft and launch vehicle at the launch site, astronaut training, and the major test programs.

To control cost, management constantly monitored commitments, obligations, and expenditures through the normal accounting techniques. During the later phases of the program, the project office maintained cost control charts on which approved programed funds were shown, as well as obligations for a given time period. From these charts, management could tell at a glance the amount of remaining unobligated funds for any given area.

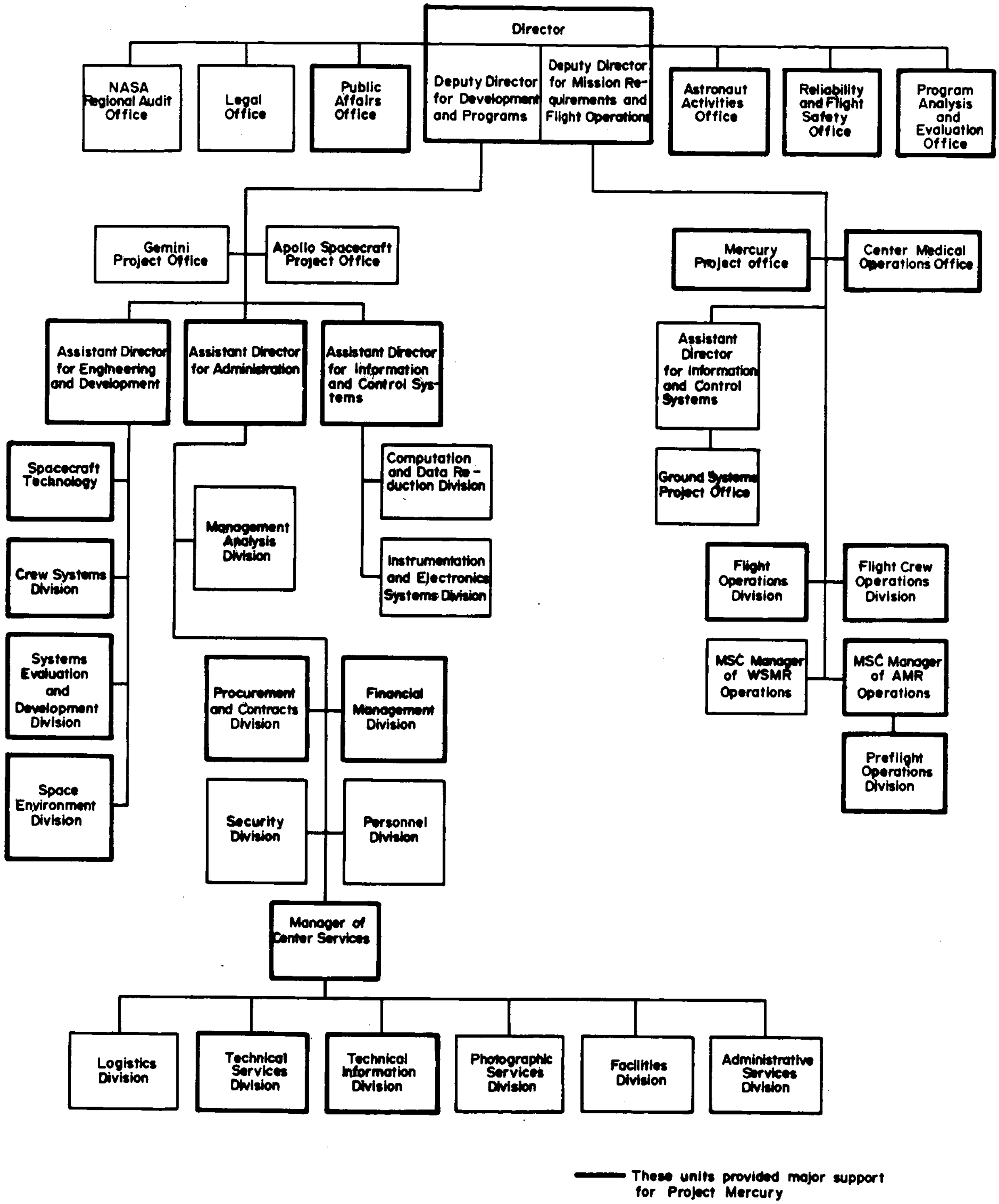


FIGURE 1-11.—Organization existing at end of Project Mercury.

In the last year and a half, the Manned Spacecraft Center applied the PERT system to cover all areas of the project. The PERT network information was analyzed and updated biweekly and provided useful information on a timely basis to make it possible to employ the use of redundant action paths or to apply additional effort when it appeared as though problems in a single, critical path would result in long delays.

Engineering, technical, configuration, and mission reviews were held as often as once a week to present up-to-date information on proposed technical changes, potential problem areas, and test results. At these meetings, the necessary decisions were made to keep the program moving along the chosen path at the desired rate. At other times, development engineering inspections were held at the contractors' plants as significant systems approached delivery status. These inspections were attended by top management and the best, most experienced supervisors, pilots, engineers, specialists, inspectors, and technicians. As a result of these inspections and thorough validating discussions, requests for mandatory corrective action were issued.

Flight safety reviews attended by top management probably constituted the most significant management tools used in Project Mercury to insure that the proper attention had been given to necessary details. These reviews were held in the days immediately before launch. In the process of ascertaining that the material required for presentation at the meetings would be acceptable, the technical work in progress was reviewed in great detail with particular emphasis being placed on results of tests, modifications, and changes that had been incorporated and the action that was taken to correct discrepancies. At the reviews, then, the questions relating to the flight readiness of the spacecraft, the launch vehicle, the crew, the network, the range, and the recovery effort could be answered in the affirmative, except in those cases where actual anomalies were discovered in the test results, data, or records during the presentation. Of course, these anomalies were then completely corrected or resolved, because no Mercury launchings were ever made in the face of known troubles or unresolved doubts of any magnitude that could affect mission success or mission safety.

Resources

Many milestones occurred during the 57 months of the project as shown in figure 1–3. Mercury history reflects 25 major flight tests in a 45-month period. It should be noted that launch preparations and flights were accomplished from two widely separated sites: Cape Canaveral, Fla., and Wallops Station, Wallops Island, Va. Twenty-three launch vehicles were utilized—seven Little Joe, six Mercury–Redstone, and ten Mercury–Atlas. Two flight tests, the off-the-pad abort and the first Little Joe flight test, did not utilize launch vehicles. Fifteen production spacecraft were utilized for the flights, some of which were used for more than one flight mission or test unit. One spacecraft was used entirely for a ground test unit.

The broad range of effort which occurred, often concurrently, during the life of the project required the services of large numbers of people, as illustrated in table 1–I. At the height of this effort there were 11 major contractors, 75 major subcontractors, and 7,200 vendors working to produce the equipment needed for Project Mercury. Also included in this endeavor were the task forces from the DOD supplying ships, planes, medical assistance, manpower, and so on in support of flight and recovery operations. During the development and qualification phase of the project, effort was expended from Langley Research Center, Lewis Research Center, George C. Marshall Space Flight Center, Goddard Space Flight Center, Ames Research Center, Wallops Station, and DOD involving hundreds of people. Colleges and universities also investigated many different and significant facets of Project Mercury. At the height of the program, there were some 650 people working directly on Project Mercury in the MSC and over 700 more in other parts of the NASA. In all, it is estimated that there were more than 2,000,000 persons located throughout the United States who directly or indirectly provided support for the Mercury Program. The general locations of the major contractors, universities, NASA centers and other government agencies are illustrated in figure 1–12.

Table 1-I.—Peak Manpower Support

Source	Approximate peak numbers	
NASA:		1,360
Direct	650	
Research and development	710	
Industry:		2,000,000
Contractors (11)	33,000	
Major subcontractors (75)	150,000	
Vendors (7,200)	1,817,000	
Department of Defense		18,000
Educational groups		168
Others		1,000
Total		2,020,528

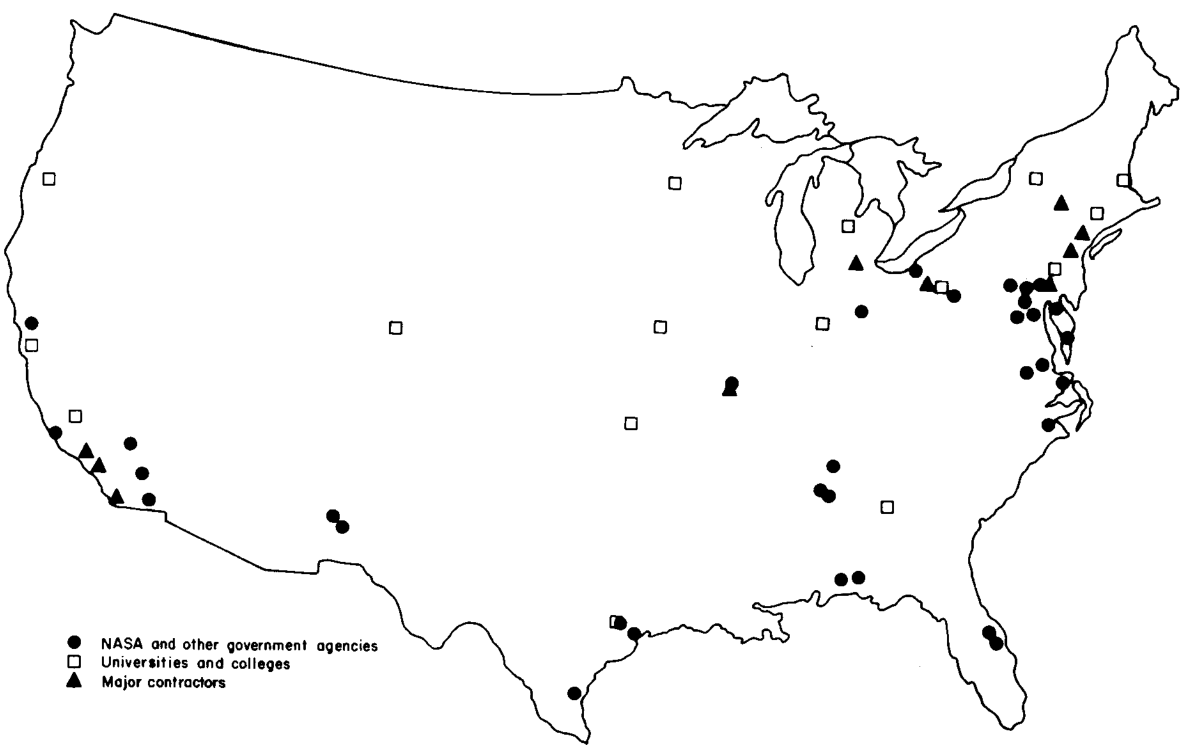


FIGURE 1-12.—Distribution of organizations in the United States that supported the project.

Lists of government agencies, prime contractors, and major subcontractors and vendors are presented in appendixes B, C, and D, respectively. A list of NASA personnel who contributed to the Mercury Project effort is presented in appendix E.

The total cost of the Mercury Program as published in the Congressional Committee Record in January 1960 was estimated to be $344,500,000. The basic objectives were fulfilled with the successful completion of the MA-6 flight and additional space experience was obtained from the MA-7, MA-8, and MA-9 missions. The latest accounting shows a total project cost of $384,131,000; however, final auditing has not been completed. These cost figures include the cost of the Mercury tracking network which will be used for manned space programs for years to come, and the cost of the operational and recovery support sup-

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Table 1-II.—Cost Breakdown

Breakdown	Percent of total		Cost in millions of dollars	
Spacecraft:		37.6		144.6
Design	8.6		33.2	
Production	5.6		21.7	
Test and flight preparation	4.2		15.9	
Subcontract	16.2		62.2	
Qualification	3.0		11.6	
	37.6		144.6	
Network		32.4		124.6
Launch vehicles		23.7		90.9
Operations		4.3		16.4
Supporting development		2.0		7.6
Total		100.0		384.1

plied for each mission. A cost breakdown is presented in table 1-II, indicating how the funds were used. It is shown that the largest part of the funds went into the development of the spacecraft and the Worldwide Tracking Network. This is not surprising since these items required complete development. About 24 percent was expended for various launch vehicles. The remainder of the funds was spent for operational expenses and for supporting research and development. A breakdown of the spacecraft costs shows that approximately equal percentages were spent on design and on production. Almost one-half of the total spacecraft cost was spent on subcontracts by the spacecraft contractor.

The peak rate of expenditures in the program, as illustrated in figure 1-13, occurred dur-

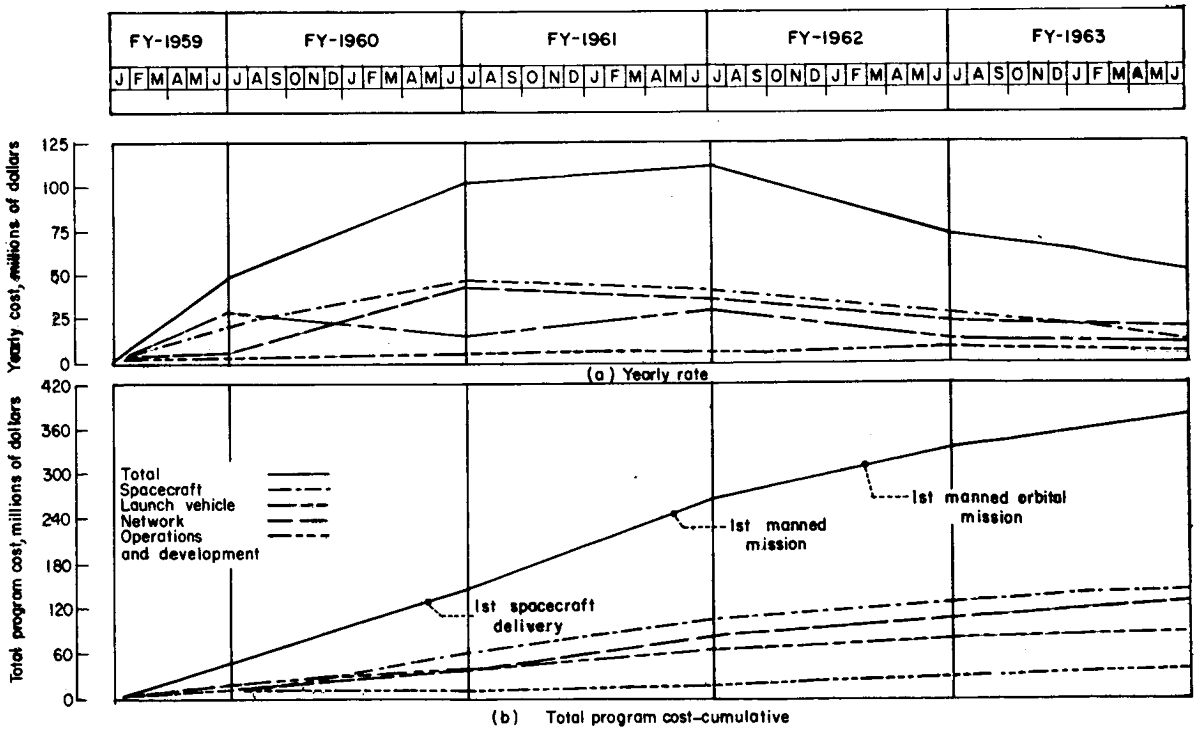

FIGURE 1-13.—Rate of expenditures and accumulated cost.

ing the fiscal year of 1961 and can be attributed to several factors. During this period, more than half of the total production spacecraft were delivered and more major flight missions were accomplished than in any other comparable time period. Launch activities were supported both at Wallops Station, Va., and at Cape Canaveral, Fla. Funds were being spent on the Worldwide Tracking Network for the coming orbital missions. The Redstone phase of flight program was nearing completion and the Atlas phase was approaching a peak. Also, much astronaut training was accomplished and the first manned ballistic flight was completed during this period.

Technical Experience

The major results obtained and the significant philosophies and techniques developed during the course of the project are grouped for discussion in the following areas: physiological and psychological responses of man in the space environment, flight and ground crew preparational procedures, and techniques and philosophy for launch preparation.

Responses of Man

The manned Mercury flights produced considerable information on human response and general physiological condition. Some of the most significant results may be summarized as follows:

(1) Results of repeated preflight and postflight physical examinations have detected no permanent changes related to the space-flight experience, although Astronauts Schirra and Cooper temporarily showed indications of orthostatic hypotension after their missions.

(2) There have been no alarming deviations from the normal, and the astronauts have proved to be exceedingly capable of making vital decisions affecting flight safety, taking prompt accurate action to correct systems deficiencies, accomplishing spacecraft control, and completing all expected pilot functions.

(3) The weightless state for the time periods of up to 34 hours has shown no cause for concern. Food and water have been consumed and the astronaut has slept. No abnormal body sensations and functions have been reported by the astronauts. The health of all of the astronauts has been good and remains so.

Not only has it been found that man can function normally in space, at least up to a maximum of 34 hours, but it has been found that he can be depended upon to operate the spacecraft and its systems whenever it is desired that he do so. On the MA–6 and MA–7 missions, the astronauts overcame severe automatic control system difficulties by manually controlling their spacecraft for retrofire and reentry. Also, on the MA–9 mission, the performance of the astronaut demonstrated that man is a valuable spacecraft system because of his judgment, his ability to interpret facts, and his ability to take corrective action in the event of malfunctions which would have otherwise resulted in a failure of the mission.

The astronauts also proved that they were qualified experimenters. As a result, the weight allocated in each succeeding manned orbital space flight increased from 11 pounds on MA–6 to 62 pounds on MA–9 for equipment not related to mission requirements. In each of these missions, the astronauts have demonstrated their ability to perform special experiments and to be a scientific observer of items of opportunity.

It can be concluded that the astronauts have proved to be qualified, necessary space systems, with flexible, wide-band-observation abilities, and have demonstrated that they could analyze situations, make decisions, and take action to back up spacecraft systems when provisions were made to give them the capability.

Crew Preparation

Studies, simulators, and training equipment for preparing flight crews and simultaneous participation of flight and ground crews in simulated missions were important to the success of the mission. This training is discussed in detail in later papers of this document. Before the final round of training and simulation began, it was found necessary to formulate and freeze a well-defined, detailed flight plan. This must be done far enough in advance of the mission to give the pilot sufficient time to train to the particular plan with the ground network teams who will support him during the mission. It has also been found to be important to avoid filling every available moment of the flight with

a planned crew or ground-station activity. Time must be available to the flight crew to manage the spacecraft systems and to investigate anomalies or malfunctions in the system and to observe and measure the unexpected. Time must be provided to allow the pilot to consider thoughtfully his reactions to the space environment and its effects upon him. He must have time to eat and drink and to obtain sufficient rest. Training in simulator devices has proved to be a valuable tool for preparing a man for space flight. Well in advance of his flight, the pilot must have detailed training in the basic systems and procedures for the mission. In addition to preparing the pilot for normal and emergency flight duties, the training must also prepare him to conduct successfully the special experiments assigned to his mission. For certain of these tasks, the pilot becomes a laboratory experimenter and must be suitably trained. So far, many different training modes have been used to good advantage. These modes include lectures by specialists, discussions with the associated scientists, familiarization sessions with the specialized flight equipment before the flight, and parallel study in the field of the experiment. During the project, the special training given the astronauts produced trained experimenters for each mission.

Launch Preparation

In the process of hardware checkout during launch preparations, it has been found essential to have detailed written test and validation procedures, procedures that are validated and followed to the most minute detail during the preliminary systems checkout and, again, during later and final systems and integrated systems checkouts. It is necessary for the procedures to be so written that even small anomalies become readily apparent to those persons involved in the checkout. These persons must be so trained and indoctrinated that they are always watchful for anomalies which would be direct or indirect indications that the hardware may be approaching failure. Checkouts are not completed at the end of the detailed procedures, for it has been found that the data accumulated during a checkout procedure may reveal, upon detailed analyses, further symptoms that all is not well within a system. Finally, the Mercury personnel have developed and adhered to a philosophy that is believed to be a basic reason for Mercury's operational success. This philosophy is that Mercury launchings will not take place in the face of known troubles or in the face of unresolved doubts of any magnitude that could possibly affect mission success or flight safety. It is believed that adherence to this philosophy is of utmost importance to success of any manned space flight program.

Areas for Improvement

A list of those general technical areas that appeared to be either the source of, or a major contributing factor to the problems that repeatedly cost the project time and money would include design requirements, qualification practices, definition of standards, tests and validation procedures, and configuration management. The conditions and effects described in these areas are not unique to this project, but represent those that generally exist in the aerospace field. Therefore, improvements in these areas would be beneficial in reducing the number of discrepancies that may potentially cause schedule delays and rising costs. Discussion of these areas will reveal that in most trouble areas careful and continuing attention to detail and quality assurance program were not as effective in the aerospace industry as necesary. It is believed that the need for improvements has become clear and that the changes for the space flight era are beginning to be made.

Design Requirements

Requirements and philosophies applied during the detail design phase have a profound and lasting effect on the overall performance of a project; therefore, some of the more significant shortcomings observed in the design phase are emphasized. Adequate design margins must be established and they must be adequate. An example where inadequate margins were detrimental is the weight-sensitive landing system. Experience with aircraft and spacecraft designs shows that weight continues to increase with time. In Mercury, this increase was significant; and although the rate tended to decrease with time, it was present throughout the duration of the project. The orbital weight of the spacecraft increased at an average rate about 5

pounds (0.2 percent) per week during 1959 and 1960; thereafter the increase averaged less than 2 pounds per week, even after a strong weight-control program had been initiated. The overall weight increase caused an extensive requalification of the landing system because the original design did not have sufficient growth margin. During the initial design phase careful consideration should be given to the use of redundancy. There are different forms of redundancy and the correct form must be chosen for the particular application to prevent degrading the overall reliability of the system. Because of the hazards of space flight and the lack of provisions for repairing or replacing equipment in flight, it was imperative in Mercury spacecraft that all critical functions have redundant modes. The redundancy was made less automatic, as man demonstrated the capability of applying the redundant function or providing the redundancy himself.

In the design of a spacecraft, consideration must be given to accessibility of components and assemblies. More than 3,000 equipment removals were made during the launch preparations on an early spacecraft; at least 1,000 removals were performed during preparations of the other production spacecraft. The majority of these removals occurred to permit access to a failed part. It is important that the design be such that a minimum number of other components have to be disturbed when it is necessary to replace or revalidate a component.

Since man first began making things, particularly with machines that could produce identical copies, he has found himself in the position where interchangeability is a combination of a blessing and a trap. Time and time again airplanes, automobiles, and other types of systems have had troubles and faults, because things that could be connected wrong have been connected wrong, regardless of printed instructions, colors, or common sense. Therefore, it is imperative that electrical connectors, mechanical components, and pneumatic and liquid connectors be so designed that they cannot physically be assembled in the wrong orientation or in the improper order. Experience shows clearly that this requirement cannot be overemphasized. Mismated or misconnected parts continued throughout the project to ruin components, give false indications of trouble, and result in improper functions that can cause test failure during the life of the project.

In the design of equipment for specific applications, consideration must be made for the shelf-life periods, including a margin for delays and extensions to the schedule. Occasionally in Mercury, these periods were not adequate and some equipment had to be replaced because the lifetime limit had been exceeded while still in storage.

Still another and often overlooked consideration is compatibility of materials. This may be related to the materials themselves, to the environment, or, in the case of manned vehicles, to the sensitivity of the man. In any event, care must be taken to see that only those materials properly approved for use in the vehicle are actually used. Time and money were expended in Mercury to rectify cases where improper materials were found in the systems because someone had failed to follow the approved materials list.

Qualification Practices

Complete and appropriate qualification of components, assemblies, subsystems, and systems is essential for reliable performance of space equipment. In the design of the Mercury spacecraft, allowances were made for the unknown environment of the planned manned space-flight missions, by conservatism in design, by redundancy of equipment in systems, and, most important, by component qualification testing through ranges of environmental conditions that were believed to exceed the real conditions. The exact conditions that the components and equipment would be subjected to during Mercury space flights, of course, was unknown prior to the time of the flights. Therefore, care was taken in selecting the qualification conditions because underqualification could result in inflight failures, and drastic overqualification could cause unnecessary delays and high costs in the program. The selected qualification conditions proved to represent the actual environment conditions very well. Some modifications to the specifications were made as the project progressed to make allowances for specific environments, such as local heating in equipment areas and system-induced electrical "glitches." Complete coverage of conditions is important, but not sufficient if the qualification is not also appropriate. During the MA–9 mis-

sion, equipment faults occurred late in the mission which resulted in the failure of the automatic control system and required Astronaut Cooper to make his retromaneuver and reentry manually. These faults, which occurred in the electrical circuitry interfaces of the automatic control system, were caused by the accumulation of moisture. The components that suffered these faults had passed the Mercury humidity and moisture qualification tests; however, detail investigation revealed that one inappropriate step had occurred. The qualification procedures were set up so that the equipment was functionally validated before the test; however, during exposure to humid air and moisture, it was not functionally operated because it was not convenient to do so in the test facility. While it was being prepared for the posttest validation, it was given an opportunity to do some drying. The obvious fault was that the equipment was not required to operate during the entire course of the test. Of course, the weightless condition could not be simulated in these or any other ground tests and it is quite likely that this omission also played a role in this flight failure.

To be complete, qualification test requirements must be selected to cover all possible normal and contingent conditions and to allow for the integrated efforts that show up when a complete system is operated.

One way the qualification of a complete system has been accomplished in the project is through the use of full-scale, simulated environment tests. A spacecraft was completely outfitted with flight equipment and instrumented and tested under environmental conditions to reproduce as closely as possible the normal and abnormal, but possible, flight conditions. From these tests, it was possible to determine the effects of modifications and to demonstrate the performance of the integrated system. Almost 1,000 hours of this type of testing was accomplished, compared with less than 60 hours of actual space flight during the entire project.

Definition of Standards

It has become very apparent that certain standards that have been used for years in the aircraft industry must be revised and tightened to make them satisfactory for application to aerospace equipment. Among these are shop practices; for example, those practices used in preparing electrical wiring must be reevaluated to assure that each step is accomplished in a manner that meets high-quality standards. Insulation stripping, soldering, crimping or welding, and cleaning processes must be accomplished without degrading the materials and in such a way that the quality of the work can be verified. Requirements must be made more rigorous and must be thoroughly understood by the people performing the operations, by their supervisors, and by the inspectors to insure continuing high quality work.

Some space equipment is designed to close tolerances which make it very sensitive to contamination in any form; therefore, it is imperative that steps be taken to assure that proper and consistent cleanliness standards are set up throughout the manufacturing, assembly, validation, and checkout phases. A number of these cleanliness standards exist at the present time. However, what is considered clean by one standard may be dirty when compared with "clean" by a similar appearing standard. Steps are now being taken in the industry to formulate logical and consistent standards and it is necessary to implement and to enforce these standards as soon as possible to prevent recurrence of the continual difficulty caused in this project by contamination that ruined metering orifices, check valves, pressure regulators, relief valves, reducers, compressors, and other mechanical equipment, as well as electrical and electronic equipment.

Test and Validation Procedures

Checkout, test, and verification procedures must be compatible with one another and with procedures serving the same function on similar equipment at different test sites. Numerous cases of anomalies, or suspected malfunctions, and failed equipment have been traced to improper or incompatible test procedures and test mediums or equipment. Also, it was found that careful attention to test techniques is essential; otherwise equipment can be damaged because connections are made improperly or dirt can be introduced into the equipment by the test equipment. It has been found that test techniques must be tightened, verified, analyzed, and written in detail to lessen the chance for inadvertent steps to ruin the operation or give false assurance.

Configuration Control

During the course of the project, considerable effort was expended by NASA and its contractors in maintaining an accurate definition of system configuration so that configuration management could be properly maintained. Much of this was manual effort that could not respond as rapidly to changes and interrogations as desired. At least 12 major documents, some of which were updated continually, some periodically, and some for each mission, were used to present the necessary information which was summarized for the desired definition. Component identification, which is essential to component traceability, also was often a tedious, time-consuming, and inaccurate process. To provide for adequate configuration control, it is important that vital information of systems, subsystems, and components be gathered at a central point. Then, provisions must be made to view this information from appropriate levels and directions so that accurate and responsive configuration management can be accomplished. Eventual incorporation of such a system on a national scale would provide a retrievable file to insure maximum use of technical experience and to lessen the chance of repeated errors.

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